

MISSION SERVICES PROGRAM OFFICE

**Ka-Band Transition Product
Ground Network
Ka-Band Ground Terminal
Demonstration Test Report**

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National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

Ka-Band Transition Product Ground Network Ka-Band Ground Terminal Demonstration Test Report

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Preface

This Ground Network (GN) Ka-Band Ground Terminal Demonstration Test Report states the results of the Ka-Band Transition Product Ka-Band Ground Terminal Demonstration that was conducted at the Wallops Flight Facility (WFF) in February 2003, May 2003, and October 2003.

This document is under the internal configuration management of the Ka-Band Transition Product Design Lead. Proposed changes to this document should be submitted to the Ka-Band Transition Product Design Lead along with supportive material justifying the change. Changes to this document shall be made by complete revision. Questions and proposed changes concerning this document shall be addressed to:

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Table Of Contents

SECTION 1. EXECUTIVE SUMMARY.....	1-1
1.1 BER PORTION OF DEMONSTRATION.....	1-1
1.2 ANTENNA AUTOTRACKING PORTION OF DEMONSTRATION	1-2
SECTION 2. OVERVIEW	2-1
2.1 BACKGROUND	2-1
2.1.1 <i>Reasons For NASA Ka-Band Programs.....</i>	<i>2-1</i>
2.1.2 <i>NASA/GSFC Ka-Band Spectrum For GN</i>	<i>2-1</i>
2.1.3 <i>Ka-Band Transition Product.....</i>	<i>2-1</i>
2.2 OBJECTIVES OF KA-BAND GROUND TERMINAL DEMONSTRATION.....	2-1
2.3 SCOPE OF DEMONSTRATION	2-1
2.4 APPLICABLE DOCUMENTS	2-2
SECTION 3. TEST APPROACH.....	3-1
3.1 TEST SYSTEM.....	3-1
3.2 REQUIREMENTS	3-1
3.3 TEST OVERVIEW	3-1
3.3.1 <i>General.....</i>	<i>3-1</i>
3.3.2 <i>High Data Rate BER Demonstration Details.....</i>	<i>3-2</i>
3.3.3 <i>Antenna Acquisition/Tracking Demonstration.....</i>	<i>3-5</i>
SECTION 4. TEST EQUIPMENT.....	4-1
SECTION 5. TEST CONDUCT	5-1
5.1 KATP TEST TEAM PERSONNEL	5-1
5.1.1 <i>Test Director Responsibilities</i>	<i>5-1</i>
5.1.2 <i>WFF Engineering Personnel Responsibilities</i>	<i>5-1</i>
5.1.3 <i>Helicopter Pilots and Technicians</i>	<i>5-1</i>
5.2 PROCEDURE CONTROL	5-1
5.2.1 <i>During Test.....</i>	<i>5-1</i>
5.2.2 <i>After Test</i>	<i>5-1</i>
SECTION 6. RESULTS FOR BER PORTION OF DEMONSTRATION.....	6-1
6.1 INTRODUCTION	6-1
6.2 BACK-TO-BACK LOOP TESTS.....	6-4
6.3 MEDIUM LOOP TESTS	6-13
6.4 END-TO-END LOOP TESTS.....	6-22
6.5 SUMMARY OF RESULTS.....	6-31
6.5.1 <i>Ka-Band Ground Terminal Implementation Loss Performance</i>	<i>6-31</i>
6.5.2 <i>Minimum Prec</i>	<i>6-35</i>
6.5.3 <i>Spectrum Analyzer Results</i>	<i>6-35</i>
6.5.4 <i>Eye Pattern Results</i>	<i>6-35</i>
6.6 TEST RECEIVER PERFORMANCE DURING BER DEMONSTRATION	6-36

SECTION 7. RESULTS OF ANTENNA AUTOTRACKING TEST	7-1
7.1 GROUND TERMINAL AND HELICOPTER TEST CONFIGURATION	7-1
7.2 TEST METHODS	7-1
7.3 TEST RESULTS	7-6
SECTION 8. CONCLUSIONS	8-1
SECTION 9. ACRONYMS	9-1

Tables

TABLE 1-1. SUMMARY OF KA-BAND GROUND TERMINAL DEMONSTRATION END-TO-END RESULTS.....	1-1
TABLE 4-1. TEST EQUIPMENT FOR BER TESTS	4-1
TABLE 4-2. TEST EQUIPMENT ON HELICOPTER DURING ANTENNA AUTOTRACK TESTS.....	4-2
TABLE 6-1. BACK-TO-BACK 50 MBPS - 600 MBPS TEST UNIT SETTINGS/CONFIGURATIONS	6-7
TABLE 6-2. BACK-TO-BACK 50 MBPS - 600 MBPS IMPLEMENTATION LOSS RESULTS	6-8
TABLE 6-3. MEDIUM LOOP 50 MBPS - 600 MBPS TEST UNIT SETTINGS/CONFIGURATIONS	6-16
TABLE 6-4. MEDIUM LOOP 50 MBPS - 600 MBPS IMPLEMENTATION LOSS RESULTS	6-17
TABLE 6-5. END-TO-END 50 MBPS - 600 MBPS TEST UNIT SETTINGS/CONFIGURATIONS.....	6-25
TABLE 6-6. END-TO-END 50 MBPS - 600 MBPS IMPLEMENTATION LOSS RESULTS.....	6-26
TABLE 6-7. SUMMARY OF 600 MBPS RESULTS FOR ALL TEST CONFIGURATIONS.....	6-33
TABLE 6-8. SUMMARY OF 600 MBPS COMPUTER SIMULATION RESULTS	6-34
TABLE 7-1. ANTENNA AUTOTRACK TEST EVENTS AND RESULTS.....	7-6

Figures

FIGURE 3-1. BER DEMONSTRATION TEST CONFIGURATION (END-TO-END TEST).....	3-3
FIGURE 3-2. BER LOOP-BACK TEST CONFIGURATIONS.....	3-4
FIGURE 3-3. ANTENNA AUTOTRACK TEST CONFIGURATION.....	3-6
FIGURE 6-1. PERMANENT KA-BAND GROUND TERMINAL CONFIGURATION.....	6-2
FIGURE 6-2. TEST CONFIGURATION STAGES	6-3
FIGURE 6-3. BACK-TO-BACK LOOP TEST CONFIGURATION (50 MBPS, 300 MBPS, AND 450 MBPS).....	6-5
FIGURE 6-4. BACK-TO-BACK LOOP TEST CONFIGURATION (600 MBPS).....	6-6
FIGURE 6-5. BACK-TO-BACK 50 MBPS - 600 MBPS EB/NO RESULTS.....	6-8
FIGURE 6-6. SPECTRUM ANALYZER PLOT, BACK-TO-BACK, 50 MBPS.....	6-9
FIGURE 6-7. SPECTRUM ANALYZER PLOT, BACK-TO-BACK, 300 MBPS.....	6-9
FIGURE 6-8. SPECTRUM ANALYZER PLOT, BACK-TO-BACK, 450 MBPS.....	6-10
FIGURE 6-9. SPECTRUM ANALYZER PLOT, BACK-TO-BACK, 600 MBPS.....	6-10
FIGURE 6-10. EYE PATTERN PLOT, BACK-TO-BACK, 50 MBPS	6-11
FIGURE 6-11. EYE PATTERN PLOT, BACK-TO-BACK, 300 MBPS	6-11
FIGURE 6-12. EYE PATTERN PLOT, BACK-TO-BACK, 450 MBPS	6-12
FIGURE 6-13. EYE PATTERN PLOT, BACK-TO-BACK, 600 MBPS	6-12
FIGURE 6-14. MEDIUM LOOP TEST CONFIGURATION (50 MBPS, 300 MBPS, AND 450 MBPS).....	6-14
FIGURE 6-15. MEDIUM LOOP TEST CONFIGURATION (600 MBPS)	6-15
FIGURE 6-16. MEDIUM LOOP 50 MBPS - 600 MBPS EB/NO RESULTS.....	6-17
FIGURE 6-17. SPECTRUM ANALYZER PLOT, MEDIUM LOOP, 50 MBPS.....	6-18
FIGURE 6-18. SPECTRUM ANALYZER PLOT, MEDIUM LOOP, 300 MBPS.....	6-18
FIGURE 6-19. SPECTRUM ANALYZER PLOT, MEDIUM LOOP, 450 MBPS.....	6-19
FIGURE 6-20. SPECTRUM ANALYZER PLOT, MEDIUM LOOP, 600 MBPS.....	6-19
FIGURE 6-21. EYE PATTERN PLOT, MEDIUM LOOP, 50 MBPS	6-20
FIGURE 6-22. EYE PATTERN PLOT, MEDIUM LOOP, 300 MBPS.....	6-20

FIGURE 6-23. EYE PATTERN PLOT, MEDIUM LOOP, 450 MBPS.....	6-21
FIGURE 6-24. EYE PATTERN PLOT, MEDIUM LOOP, 600 MBPS.....	6-21
FIGURE 6-25. END-TO-END TEST CONFIGURATION (50 MBPS, 300 MBPS, AND 450 MBPS)	6-23
FIGURE 6-26. END-TO-END TEST CONFIGURATION (600 MBPS).....	6-24
FIGURE 6-27. END-TO-END 50 MBPS - 600 MBPS EB/NO RESULTS.....	6-26
FIGURE 6-28. SPECTRUM ANALYZER PLOT, END-TO-END, 50 MBPS	6-27
FIGURE 6-29. SPECTRUM ANALYZER PLOT, END-TO-END, 300 MBPS	6-27
FIGURE 6-30. SPECTRUM ANALYZER PLOT, END-TO-END, 450 MBPS	6-28
FIGURE 6-31. SPECTRUM ANALYZER PLOT, END-TO-END, 600 MBPS	6-28
FIGURE 6-32. EYE PATTERN PLOT, END-TO-END, 50 MBPS	6-29
FIGURE 6-33. EYE PATTERN PLOT, END-TO-END, 300 MBPS	6-29
FIGURE 6-34. EYE PATTERN PLOT, END-TO-END, 450 MBPS	6-30
FIGURE 6-35. EYE PATTERN PLOT, END-TO-END, 600 MBPS	6-30
FIGURE 6-36. 600 MBPS RESULTS FOR ALL TEST CONFIGURATIONS.....	6-32
FIGURE 6-37. 600 MBPS MINIMUM PREC CALCULATION.....	6-35
FIGURE 7-1. GROUND TERMINAL AND HELICOPTER TEST CONFIGURATION	7-2
FIGURE 7-2. HELICOPTER TEST EQUIPMENT.....	7-3
FIGURE 7-3. KA-BAND CIRCULAR POLARIZED (RHCP & LHCP) BROADBEAM ANTENNA (CLOSE-UP)	7-4
FIGURE 7-4. KA-BAND CIRCULAR POLARIZED (RHCP AND LHCP) BROADBEAM ANTENNA.....	7-4
FIGURE 7-5. S-BAND BLADE ANTENNA MOUNTED ON BOTTOM OF HELICOPTER.....	7-5
FIGURE 7-6. TEST EVENT 1, ELEVATION ANGLE, 25.8 GHZ RHCP CW	7-7
FIGURE 7-7. TEST EVENT 1, X ANGLE, 25.8 GHZ RHCP CW.....	7-7
FIGURE 7-8. TEST EVENT 1, X ANGULAR RATE, 25.8 GHZ RHCP CW	7-8
FIGURE 7-9. TEST EVENT 1, Y ANGLE, 25.8 GHZ RHCP CW.....	7-8
FIGURE 7-10. TEST EVENT 1, Y ANGULAR RATE, 25.8 GHZ RHCP CW	7-8
FIGURE 7-11. TEST EVENT 2, ELEVATION ANGLE, 26.5 GHZ RHCP, 150 MBPS QPSK.....	7-9
FIGURE 7-12. TEST EVENT 2, X ANGLE, 26.5 GHZ RHCP, 150 MBPS QPSK.....	7-9

FIGURE 7-13. TEST EVENT 2, X ANGULAR RATE, 26.5 GHZ RHCP, 150 MBPS QPSK	7-9
FIGURE 7-14. TEST EVENT 2, Y ANGLE, 26.5 GHZ RHCP, 150 MBPS QPSK.....	7-10
FIGURE 7-15. TEST EVENT 2, Y ANGULAR RATE, 26.5 GHZ RHCP, 150 MBPS QPSK	7-10
FIGURE 7-16. TEST EVENT 3, ELEVATION ANGLE, 26.7 GHZ RHCP CW	7-10
FIGURE 7-17. TEST EVENT 3, X ANGLE, 26.7 GHZ RHCP CW	7-11
FIGURE 7-18. TEST EVENT 3, X ANGULAR RATE, 26.7 GHZ RHCP CW	7-11
FIGURE 7-19. TEST EVENT 3, Y ANGLE, 26.7 GHZ RHCP CW	7-11
FIGURE 7-20. TEST EVENT 3, Y ANGULAR RATE, 26.7 GHZ RHCP CW	7-12
FIGURE 7-21. TEST EVENT 4, ELEVATION ANGLE, 26.7 GHZ LHCP CW	7-12
FIGURE 7-22. TEST EVENT 4, X ANGLE, 26.7 GHZ LHCP CW	7-12
FIGURE 7-23. TEST EVENT 4, X ANGULAR RATE, 26.7 GHZ LHCP CW	7-13
FIGURE 7-24. TEST EVENT 4, Y ANGLE, 26.7 GHZ LHCP CW	7-13
FIGURE 7-25. TEST EVENT 4, Y ANGULAR RATE, 26.7 GHZ LHCP CW	7-13

Section 1. Executive Summary

This Ka-Band Ground Terminal demonstration test report states the results of the Ka-Band Transition Product (KaTP) Ka-Band Ground Terminal Demonstration that the KaTP test team conducted at the Wallops Flight Facility (WFF) during three separate test periods between February 2003 and October 2003. As part of the KaTP project, the KaTP team developed and implemented a Ka-Band Ground Terminal with a 5.4-meter antenna at WFF for demonstration purposes. The KaTP test team conducted the bit error rate (BER) portion of the demonstration at data rates of 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps.

Also, the KaTP team conducted Ka-band antenna autotrack testing with a helicopter.

1.1 BER Portion Of Demonstration

Table 1-1 lists the implementation losses that were measured during the medium loop and end-to-end BER portions of the demonstration for uncoded 50 Mbps, uncoded 300 Mbps, uncoded 450 Mbps, and uncoded 600 Mbps. During the End-To-End BER portion of the demonstration, the test team used a boresite tower as the transmit source because an orbiting spacecraft was not available for testing. The medium loop test was an internal loop-back test that was conducted inside the Ka-Band Ground Terminal, but the medium loop test configuration did include all of the significant ground terminal components, except for the 5.4 meter antenna. The boresite tower was located about 2 km from the Ka-Band Ground Terminal.

Table 1-1. Summary Of Ka-Band Ground Terminal Demonstration End-To-End Results

Data Rate	Bit Error Rate	Measured Medium Loop Implementation Loss	Measured End-To-End Implementation Loss
50 Mbps	10^{-5}	3.4 dB	3.7 dB
	10^{-7}	4.4 dB	5.1 dB
300 Mbps	10^{-5}	2.9 dB	3.7 dB
	10^{-7}	3.5 dB	4.3 dB
450 Mbps	10^{-5}	3.1 dB	4.7 dB
	10^{-7}	3.9 dB	5.8 dB
600 Mbps	10^{-5}	4.1 dB	5.5 dB
	10^{-7}	6.5 dB	8.7 dB

The Ka-Band Ground Terminal can support data rates up to 600 Mbps, but the implementation loss values are higher than desired for an operational link, especially at 600 Mbps. However, the BER portion of the demonstration provides a baseline for the Ka-Band Ground Terminal performance and shows that the Goddard Space Flight Center (GSFC) can consider using the Ka-Band Ground Terminal as a test-bed to support Ka-Band technology developments like the GSFC High Rate User Ka-Band Phased Array Antenna.

The KaTP project understands that the 5.5 dB implementation loss for a 10^{-5} BER at 600 Mbps should be reduced to support an operational GN data service. However, approximately 1.4 dB of the loss can be attributed to the available test transmitter system at the boresite tower. This value was determined through medium loop tests that included all of the significant ground terminal components except for the 5.4 meter antenna, and resulted in an implementation loss value of 4.1 dB. Computer simulations have indicated that a 3.36 dB implementation loss can be achieved by adding a cable equalizer that removes the gain versus frequency tilt characteristic and parabolic phase characteristic that exist in the Ka-Band Ground Terminal. Additionally, computer simulations have indicated that a 2.79 dB implementation loss can be achieved by adding an adaptive baseband equalizer (ABBE) rather than a cable equalizer to the Ka-Band Ground Terminal. Also, the demonstration testing was conducted without channel coding, therefore, coding could also be used to reduce the effects of signal distortions.

Also, the test receiver performance at 600 Mbps should be improved before the receiver is used operationally at 600 Mbps. The 600 Mbps performance during the demonstration was achieved only by bypassing the receiver bit synchronizer and using the Agilent 86130A Bit Error Rate Test System (BERTS) as the bit synchronizer. Using the BERTS as a bit synchronizer is not possible in an operational environment because the data is not accessible after the BERTS.

If better implementation loss performance is required for an operational system, the KaTP project recommends that GSFC install a cable equalizer or an ABBE in the Ka-Band Ground Terminal, use coding, and/or use an improved receiver.

When a Ka-band orbiting spacecraft becomes available for BER testing at any data rate, the test team recommends that the GSFC conduct BER tests with that spacecraft at Ka-band.

1.2 Antenna Autotracking Portion Of Demonstration

During the antenna autotracking portion of the demonstrations, the KaTP test team successfully demonstrated that the Ka-Band Ground Terminal can manually acquire and autotrack a helicopter. The helicopter was used as the moving Ka-Band signal source during the demonstration because a Ka-band orbiting spacecraft was not available for testing. Therefore, when a Ka-band orbiting spacecraft becomes available for testing, the test team recommends that GSFC conduct an antenna autotracking demonstration with the spacecraft. The antenna autotrack demonstration with an orbiting spacecraft should verify the automatic Ka-band acquisition capability while using the program track mode for initial acquisition.

Section 2. Overview

2.1 Background

2.1.1 Reasons For NASA Ka-Band Programs

Currently, the NASA Ground Network (GN) provides direct space-to-Earth downlink support to near-Earth science missions at S-Band and X-band. Data rates are limited when using S-band and X-band.

NASA initiated the KaTP project in an effort to migrate high data rate GN customers to Ka-band. This effort to migrate customers to Ka-band for direct space-to-Earth downlinks was driven by the following:

1. NASA's forecasts for Earth Exploration-Satellite mission requirements reflect the need for telemetry data rates up to at least 1.2 Gbps which exceeds the capacity of the spectrum available at S-Band and X-band.
2. The need to reduce the potential for interference in existing GN frequency bands.

2.1.2 NASA/GSFC Ka-Band Spectrum For GN

The 1992 World Administrative Radio Conference (WARC-92) allocated the 25.5 to 27.0 GHz band to the Earth Exploration-Satellite service, allowing for direct space-to-Earth links between a Ka-band ground station and space research or earth exploration spacecraft.

2.1.3 Ka-Band Transition Product

In early 2000, the Ka-Band Transition Product (KaTP) was established by the Goddard Space Flight Center (GSFC) Mission Services Program Office to accomplish the following GN goal:

- Develop and procure a Ka-Band Ground Terminal at WFF for demonstration purposes.

2.2 Objectives Of Ka-Band Ground Terminal Demonstration

During three separate test periods between February 2003 and October 2003, the KaTP test team conducted the KaTP Ka-Band Ground Terminal demonstration at WFF in order to accomplish the following two objectives:

1. Demonstrate that the new Ka-band Ground Terminal can operate at data rates up to 600 Mbps.
2. Demonstrate that the Ka-band ground terminal can use Ka-band autotracking to track a moving Ka-band signal source.

2.3 Scope Of Demonstration

During the BER portion of the demonstration, the KaTP test team characterized the performance of the ground terminal by:

1. Collecting Eb/No versus bit error rate (BER) data, Signal Spectra, and eye pattern data for Back-To-Back Loop, Medium Loop, and End-To-End Test Configurations.
2. Determining implementation loss at various BER points by using collected Eb/No versus BER data.
3. Assessing effects of subsystem distortions on overall End-To-End link performance by comparing data obtained during different test configurations.

During the antenna autotracking portion of the demonstration, the KaTP test team characterized the antenna autotracking performance of the ground terminal by:

1. Autotracking a NASA helicopter that provided different angular velocities and transmitted signals with different modulations, polarizations, and frequencies.
2. Collecting signal-to-noise ratio (SNR) data at the ground terminal.
3. Assessing how different antenna azimuth and elevation angles and different antenna angular velocities affected the antenna autotracking performance by recording and analyzing antenna pointing information.

2.4 Applicable Documents

- a. “Ka-Band Transition Product High Data Rate Demonstration Plan”, 450-DP-KaTP, Mission Services Program Office, GSFC, November 2002.
- b. “Ka-Band Transition Product (KaTP) System Requirements Document (SRD)”, 450-SRD-KaTP, Mission Services Program Office, GSFC, March 2002.
- c. “Ka-Band Transition Product Management Plan”, Original, 453-PMP-KaTP, Mission Services Program Office, GSFC, September 2001.
- d. “Ka-Band Transition Product Ground Network Demonstration Test Procedures”, 450-GNTP-KaTP, Mission Services Program Office, GSFC, October 2002.
- e. “Space Network Users’ Guide (SNUG)”, 450-SNUG, Mission Services Program Office, GSFC, June 2002.

Section 3. Test Approach

3.1 Test System

The system under test was the new KaTP Ka-Band ground terminal that has a 5.4-meter antenna.

3.2 Requirements

The demonstration satisfied the GN portion of the KaTP demonstration objectives listed in reference [a] that is listed under paragraph 2.4 of this document.

3.3 Test Overview

3.3.1 General

The KaTP test team, which included WFF and ITT Industries personnel, conducted the demonstration at the NASA WFF by using the new Ka-Band ground terminal and a variety of test equipment during the high data rate BER portion of the demonstration. During the helicopter/autotrack portion of the demonstration, the test team used the new Ka-Band ground terminal, a variety of test equipment, and a NASA helicopter.

The WFF Ka-band ground terminal is a stand-alone, non-operational system; therefore formal scheduling was not required.

During BER tests, a Staggered Quadrature Phase Shift Keying (SQPSK) Ka-band signal was transmitted using a test modulator. A test receiver was used to demodulate the signal and recover the I- and Q-channel data and clock signals for BER measurements.

Two main categories of demonstrations were conducted: high data rate BER demonstration tests and antenna acquisition/tracking demonstration tests. Each of these is discussed in detail below.

3.3.2 High Data Rate BER Demonstration Details

The KaTP test team conducted BER tests with a test modulator and a test receiver to meet the demonstration high data rate demonstration objective in Section 2.2 above.

Figure 3-1 depicts the demonstration Ka-band Ground Terminal, WFF bore-site tower, and End-To-End Test configuration. A pseudo-noise (PN) data generator, a high-rate test modulator, and a Ka-band test upconverter were located at the bore-site tower. A test receiver and Bit Error Rate Test Set (BERTS) were located in the ground terminal.

The KaTP test team also performed BER tests for a back-to-back loop configuration and a medium loop configuration to aid in the assessment of the system design and ground terminal subsystem distortion effects. Figure 3-2 illustrates the back-to-back loop and medium loop configurations.

To perform a back-to-back loop test as shown in Figure 3-2, the 1.2 GHz output of the modulator was connected to the 1.2 GHz input of the test receiver.

To perform a medium loop test as shown in Figure 3-2, the test team used the test Ka-band upconverter of the ground terminal to up-convert the 1.2 GHz modulator output to a Ka-band frequency of 25.7 GHz. The frequency upconversion occurred after the 1.2 GHz signal arrived at the antenna radome via the Fiber Optic Transmission System (FOTS). The 25.7 GHz output of the upconverter was coupled into the input of the LNA. Then, the signal traveled to the receiver via the same path that a customer spacecraft signal will use.

The test team performed BER measurements at 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps in order to characterize the design and performance of the ground terminal. During all BER tests, the modulator was configured for single channel, uncoded SQPSK modulation with a NRZ-L data format on each channel. The modulator generated the same Psuedo Random Bit Stream (PRBS) on each channel, with a $\frac{1}{2}$ bit offset (SQPSK) after a single PRBS was injected into the I-channel input of the modulator. The test receiver was configured for quadrature phase shift keying (QPSK) and individual I and Q channel BER measurements were performed. The KaTP test team fully characterized the system performance by isolating the BER performance on the I channel from the BER performance on the Q channel. The test team calculated the link BER by averaging the I channel and Q channel BERs.

During the tests, the KaTP test team used variable attenuators to vary the signal power in order to obtain E_b/N_0 values for BERs from 10^{-5} to 10^{-8} . The test team plotted BER vs. E_b/N_0 curves from the data points. The E_b/N_0 was calculated from the measured C/N_0 . A spectrum analyzer was placed in parallel with the receiver input. The test team electronically stored a spectrum analyzer plot on disk for each data rate. During the medium loop tests, the antenna was put in motion to verify that the motor system does not degrade the system performance. Also, eye pattern measurements were made during the tests.

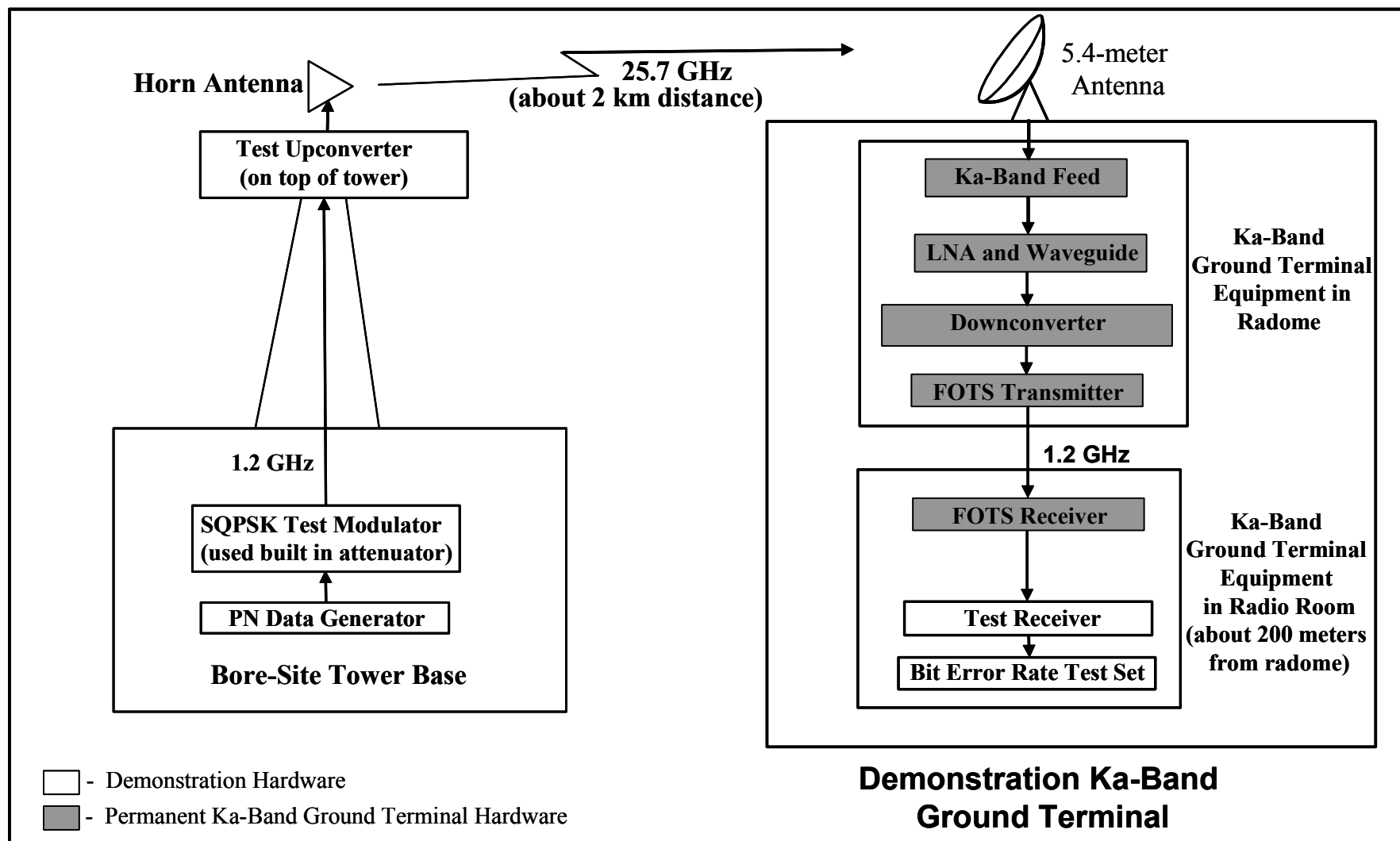


Figure 3-1. BER Demonstration Test Configuration (End-To-End Test)

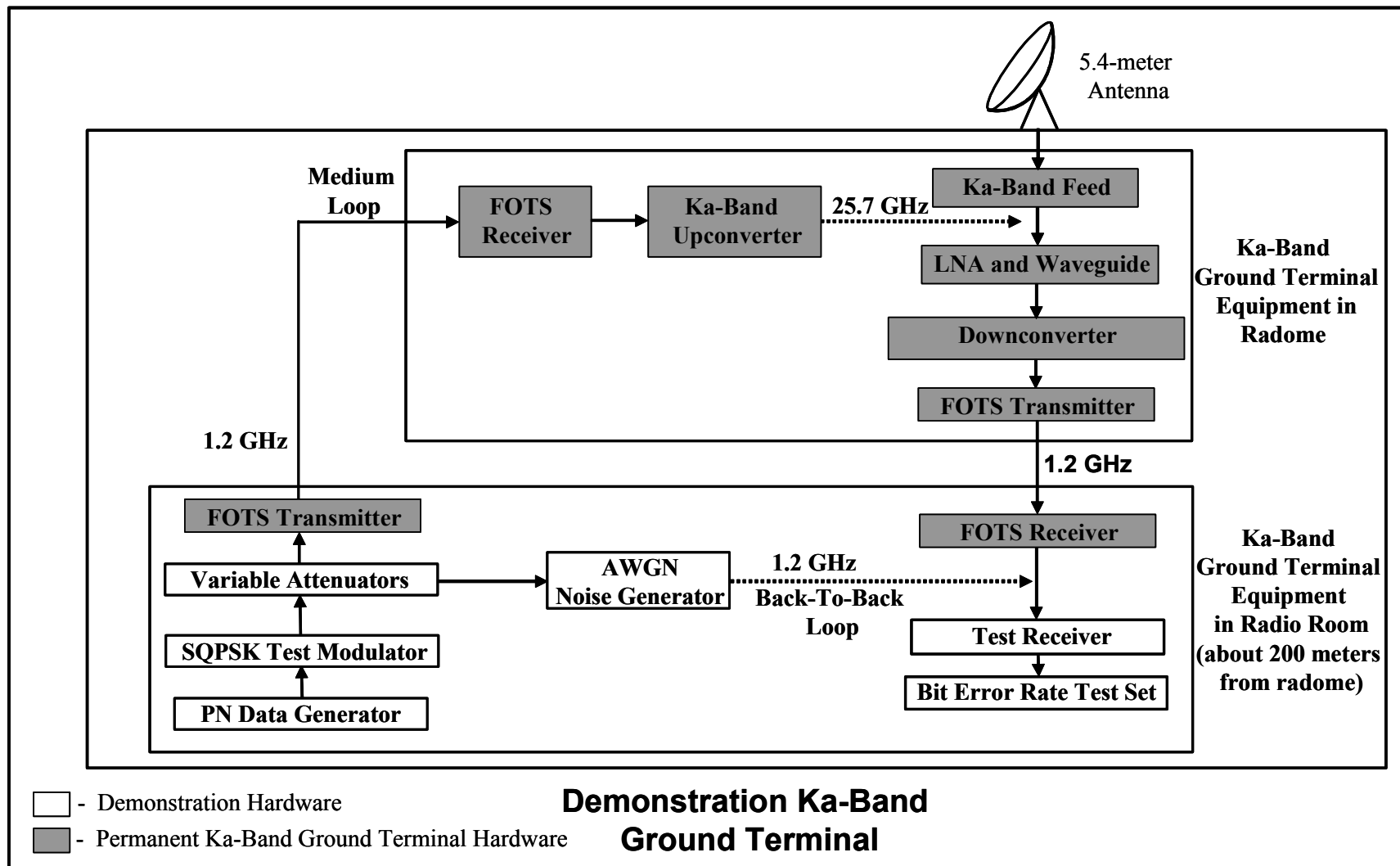


Figure 3-2. BER Loop-Back Test Configurations

3.3.3 Antenna Acquisition/Tracking Demonstration

Presently, no orbiting Ka-band spacecraft are available for testing in the 25.5 GHz to 27.0 GHz band. In order to conduct antenna autotrack tests with a moving target, Ka-band and S-band transmitters were flown on a helicopter in order to evaluate the dynamic autotrack performance of the ground terminal. The antenna acquisition demonstration was used to meet the autotrack demonstration objective in Section 2.2 above. The antenna acquisition demonstration was designed to show that the ground terminal Ka-band antenna can successfully acquire and autotrack a helicopter that is simulating a spacecraft with Low Earth Orbit (LEO) range dynamics as best as possible.

Figure 3-3 depicts the test configuration for the antenna autotrack demonstration.

The helicopter flew a four mile radius circular pattern. The test team used the manual handwheels of the 3862 Antenna Control Unit (ACU) to initially acquire the S-band signal. After S-band acquisition, the S-band autotrack was manually selected. Then after several seconds of S-band autotracking, the test team manually selected Ka-band autotrack. The helicopter alternately transmitted QPSK signals and continuous wave (CW) signals. The KaTP test team recorded all of the autotrack acquisition times and other performance characteristics.

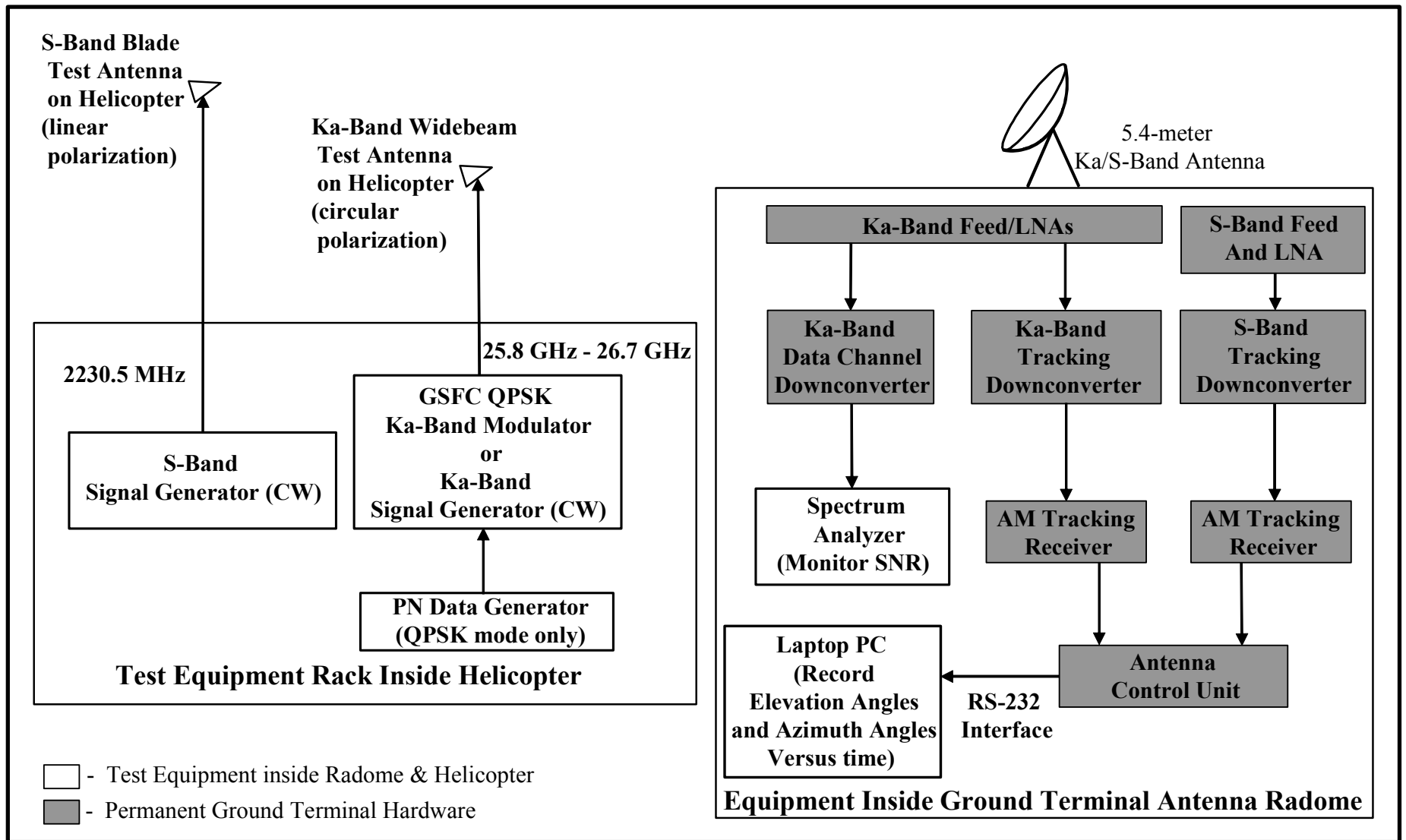


Figure 3-3. Antenna Autotrack Test Configuration

Section 4. Test Equipment

Tables 4-1 and 4-2 list all relevant test equipment that was used during the BER tests and helicopter tests, respectively. A detailed description of the permanent equipment, cabling, and subsystems of the Ka-Band Ground Terminal is provided in the Ka-Band Transition Product System Design Review document, dated December 19, 2000. The KaTP project gives special thanks to Code 567 who provided an extra BERTS unit, extra PN generator unit, and extra receiver for the BER portion of the testing. The KaTP test team project gives special thanks to the Langley Research Center's Flight Operations Office of the Airborne Systems Competency who provided the helicopter and flight crew for the antenna autotracking portion of the demonstrations. Also, the KaTP project gives special thanks to Code 569 who provided valuable support at WFF during all of the demonstration testing.

Table 4-1. Test Equipment For BER Tests

ITEM #	TEST EQUIPMENT	MANUFACTURER & TYPE NUMBER	RANGE/SPECIFICATION
1	Spectrum Analyzer	Rohde & Schwarz	a. 1.2 GHz center frequency capability for C/N ₀ measurements b. N-Type female input
2	Bit Error Rate Test System (BERTS)	Agilent 86130A	a. 25 to 600 Mbps Capability b. PRBS NRZ-L bit stream compatible c. ECL single-ended receive input
3	PN Signal Generator	Agilent 86130A	a. Generate data rates from 25 Mbps to 600 Mbps b. PRBS NRZ-L bit stream compatible with BERTS (2 ²³ -1) c. ECL differential
4	SQPSK Modulator	TSI Telsys	a. SQPSK modulation b. Single channel input for 50 Mbps to 600 Mbps NRZ-L data input c. Provide 0.5xT _b channel offset prior to modulation d. 1.2 GHz output e. Output Level: -15 to +4 dBm
5	70 dB Variable Attenuator	Agilent 8495B	a. Vary IF 1.2 GHz signal level to achieve required Eb/No b. SMA connectors c. 0 – 70 dB attenuation capability in 10 dB steps
6	11 dB Variable Attenuator	Agilent 8494B	a. Vary IF 1.2 GHz signal level to achieve required Eb/No b. SMA connectors c. 0 – 11 dB attenuation capability in 1 dB steps
7	Bore-site tower upconverter	WFF provided	a. 1.2 GHz to 25.7 GHz frequency translation.
8	High Data Rate Receiver	TSI Telsys	a. 1.2 GHz IF input b. QPSK demodulation and bit synchronization c. Separate I and Q channel outputs for QPSK d. Receiver is programmable to operate at any data rate up to 600 Mbps (300 Mbps each channel)
9	Power Divider (1 input/ 2 outputs)	Minicircuits ZFSC-2-2500	a. Can operate at 1.2 GHz b. SMA female connectors

ITEM #	TEST EQUIPMENT	MANUFACTURER & TYPE NUMBER	RANGE/SPECIFICATION
10	Cables with SMA male connectors that operate up to 1.2 GHz	Provided by WFF	a. Can operate at 1.2 GHz b. 0.5 –1.0 meter length
11	AWGN Generator	Noise/Com, model NC6112	a. Has signal combiner option. b. Has 110 dB attenuator in 1 dB steps option.
12	Oscilloscope	Infiniium 54810A	a. 4 Gsamples/sec b. Eye pattern measurements

Table 4-2. Test Equipment on Helicopter During Antenna Autotrack Tests

ITEM #	TEST EQUIPMENT	MANUFACTURER & TYPE NUMBER	RANGE/SPECIFICATION
1	S-Band blade Antenna	WFF provided	2230.5 MHz capability with widebeam.
2	Ka-Band Antenna	WFF provided	25.8 GHz to 26.7 GHz capability with approximately 100 degree beamwidth.
3	PN Data Generator	Agilent 37717C OmniBER	150 Mbps capability for injection into GSFC Ka-Band Modulator.
4	S-Band Signal Generator	Agilent ESG4432 RF Generator	Provided S-band CW signal.
5	Ka-Band Signal Generator	Agilent 83640	Provided Ka-band CW signal.
6	GSFC In-house Ka-band Modulator	Provided by GSFC Microwave & Communications Systems Branch	150 Mbps QPSK capability at 26.5 GHz.

Section 5. Test Conduct

5.1 KaTP Test Team Personnel

The KaTP test team included the following personnel:

- KaTP Test Director
- WFF Engineers
- Helicopter pilots and technicians

5.1.1 Test Director Responsibilities

- Overall responsibility for demonstration tests
- Conducted step-by-step demonstration procedures along with WFF personnel
- Documented demonstration test results

5.1.2 WFF Engineering Personnel Responsibilities

- Overall responsibility for Ka-band ground terminal, demonstration equipment, integration, check-out, and operation.
- Conducted step-by-step demonstration procedures along with test director
- Supported test director in documenting results

5.1.3 Helicopter Pilots and Technicians

Overall responsibility for helicopter support and operations during helicopter/autotracking portion of demonstration.

5.2 Procedure Control

5.2.1 During Test

During the test, the KaTP test director redlined the official demonstration test procedure.

5.2.2 After Test

The test director incorporated the redlined changes into the final test procedure.

Section 6. Results For BER Portion Of Demonstration

6.1 Introduction

This section presents the detailed demonstration results for the high data rate BER portion of the demonstration. Figure 6-1 depicts the permanent configuration of the Ka-band ground terminal. Later figures in this section depict the test receiver and other demonstration test equipment required for these demonstrations.

Before conducting the BER demonstration, WFF personnel verified that the new Ka-band ground terminal was operating properly and within the specifications defined in the KaTP Systems Requirements Document (SRD). Therefore, the demonstration started after the relevant system acceptance tests were completed.

The KaTP test team conducted the demonstration by building up the test configurations in stages to reach the final bore-site tower End-To-End Test Configuration. Figure 6-2 depicts the different test configuration stages.

Section 6.2 describes the results of the “Back-To-Back Loop” tests at 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps. The test configuration consisted of the modulator transmitting into the test receiver. The KaTP test team used the Additive White Gaussian Noise (AWGN) generator during the back-to-back loop tests.

Section 6.3 describes the results of the “Medium Loop” tests at 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps. In addition to the receiver and modulator, this test included the ground terminal test Ka-band upconverter, Fiber Optic Transmission System (FOTS), Ka-band low noise amplifier (LNA), and Ka-band downconverter. The test was conducted using the loop back test system in the Ka-band ground terminal.

Section 6.4 describes the results of the “End-To-End” tests at 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps. The end-to-end tests included a bore-site tower located at WFF.

During all tests, the KaTP test team recorded spectrum analyzer plots and eye pattern plots on disk for each data rate. For each data rate, the test team varied the E_b/N_0 for BERs from 10^{-5} to 10^{-8} . During the medium loop tests, the antenna was put in motion to verify that the motor system does not degrade the BER.

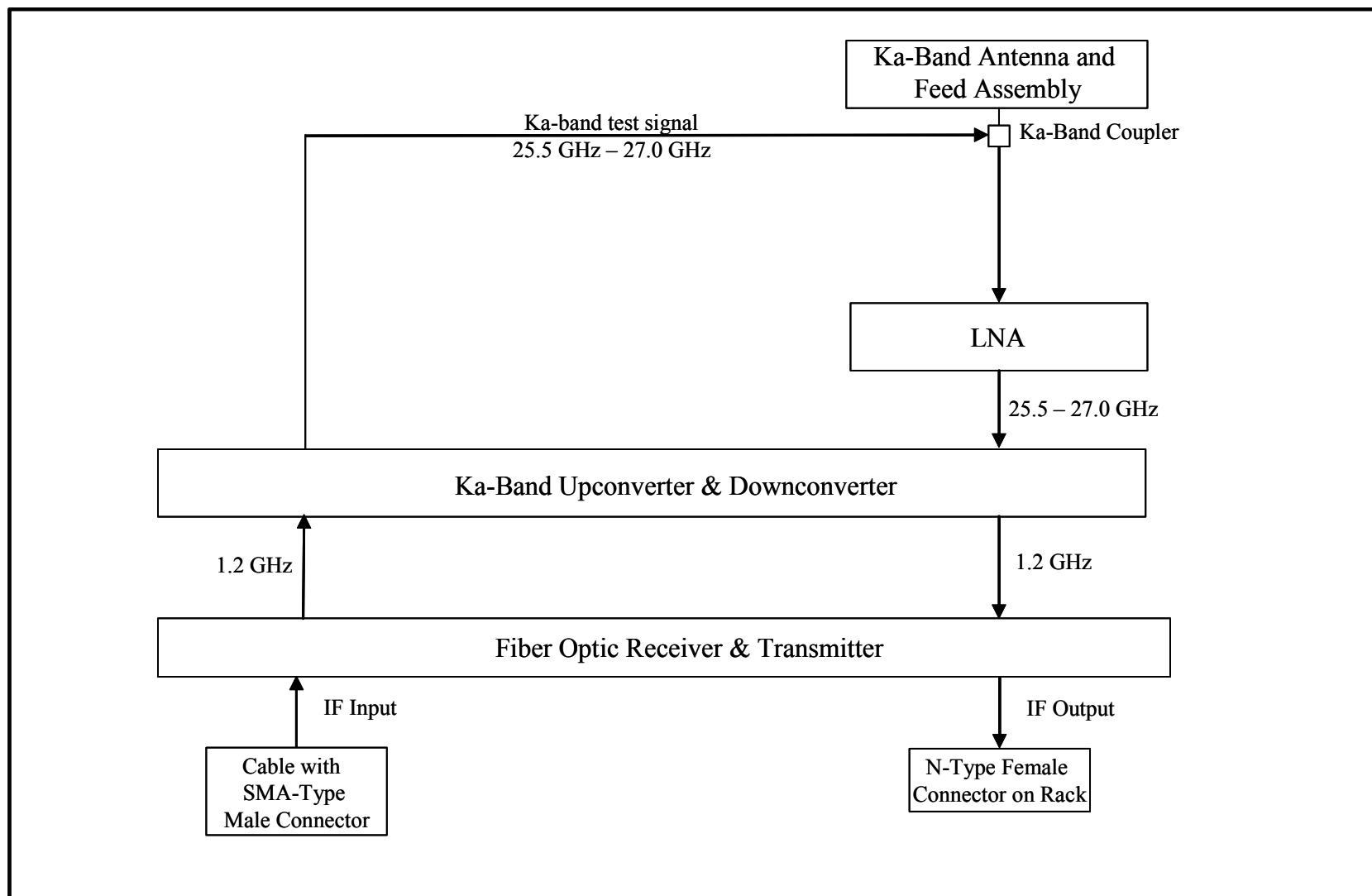


Figure 6-1. Permanent Ka-Band Ground Terminal Configuration

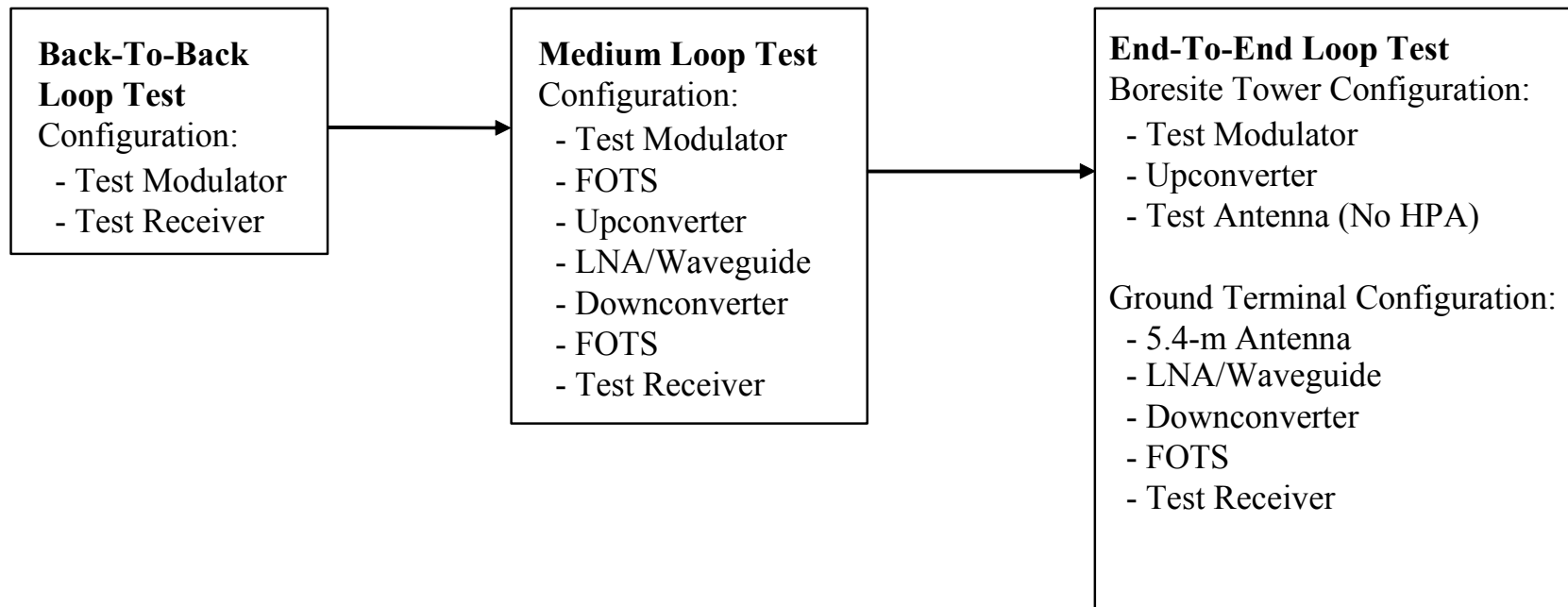


Figure 6-2. Test Configuration Stages

6.2 Back-To-Back Loop Tests

This section describes the detailed results of the Back-To-Back Loop tests at 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps. Figure 6-3 depicts the detailed back-to-back loop test configuration for the 50 Mbps, 300 Mbps, and 450 Mbps tests. Figure 6-4 depicts the detailed back-to-back test configuration for the 600 Mbps tests. For the 600 Mbps tests, the test receiver bit synchronizer was bypassed. For 600 Mbps, the test receiver did not work well when using its bit synchronizer. Therefore, the test team used the bit synchronizer function in the Agilent BERTS to conduct the bit synchronizer function. The 50 Mbps and 600 Mbps tests were conducted at WFF in October 2003. The 300 Mbps and 450 Mbps tests were conducted at WFF in May 2003.

For all data rates, the back-to-back loop tests consisted of the modulator transmitting into the test receiver. The KaTP test team measured the E_b/N_0 values for BERs from 10^{-5} to 10^{-8} . The PN data generator provided data and clock signals to the modulator. The KaTP test team used the noise generator to generate a constant noise floor that was at about the same level as the noise floor that exists at the 1.2 GHz IF output of the ground terminal. The signal level at the modulator output was varied with variable attenuators in order to generate different E_b/N_0 values. The spectrum analyzer was used to make C/N_0 measurements. The test team calculated the E_b/N_0 values from the C/N_0 measurement data.

Table 6-1 summarizes the test equipment settings and configurations that were used for the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps tests.

Figure 6-5 depicts the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps E_b/N_0 results for the back-to-back loop tests. The I & Q channels were averaged in order to generate the curves in Figure 6-5. Table 6-2 lists the implementation loss results for the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps tests. Implementation loss was obtained by subtracting the theoretical curve from the actual measured curve.

Figures 6-6 to 6-9 depict the spectrum analyzer plots for the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps Back-To-Back tests. Figures 6-10 to 6-13 depict the eye pattern plots for 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps. The eye pattern data was taken at the output of the test receiver matched filter (video output port of receiver). The 50 Mbps eye pattern shows a signal with slightly excessive distortion characteristics which explains the non-optimum performance at 50 Mbps.

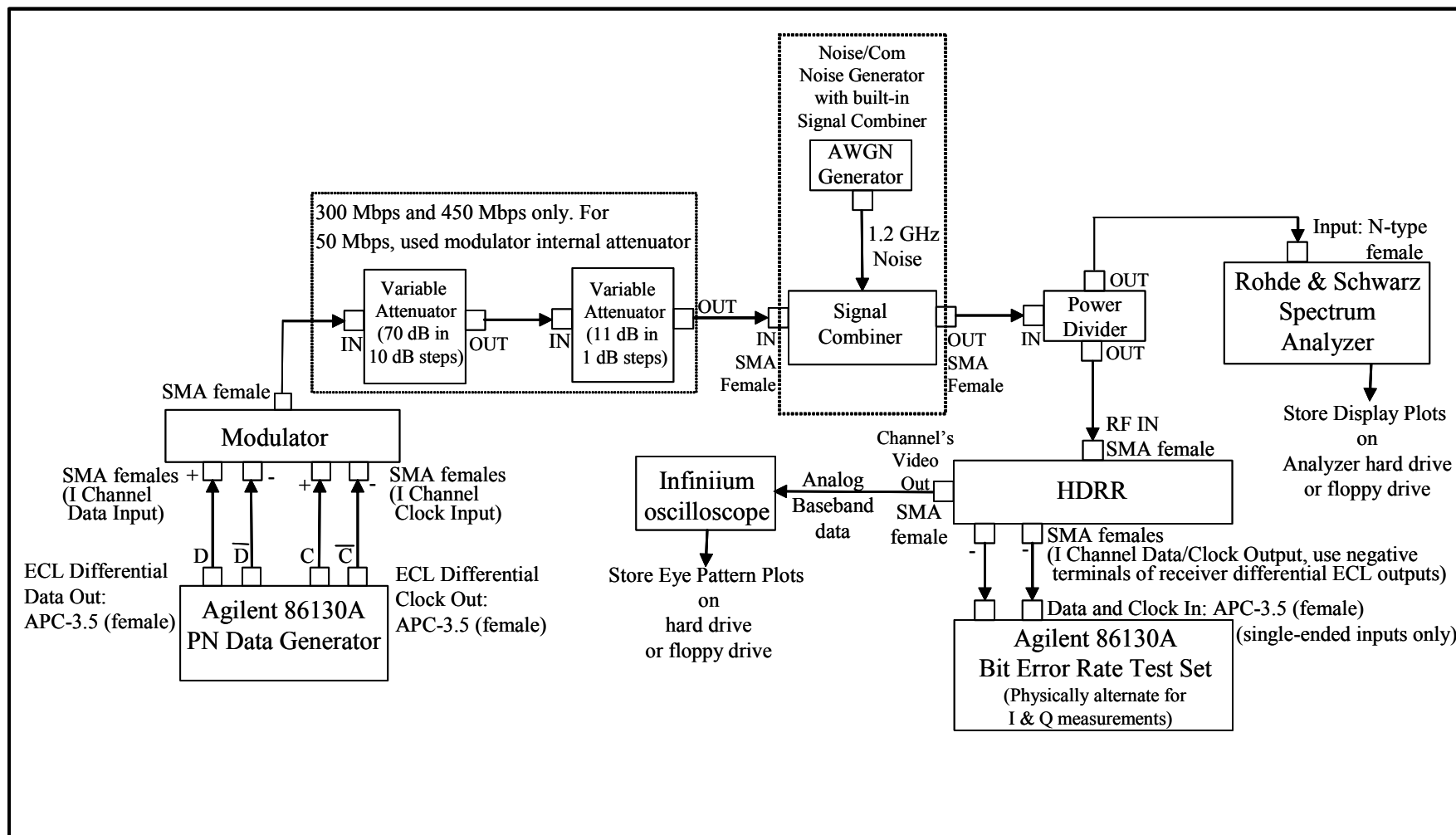


Figure 6-3. Back-To-Back Loop Test Configuration (50 Mbps, 300 Mbps, and 450 Mbps)

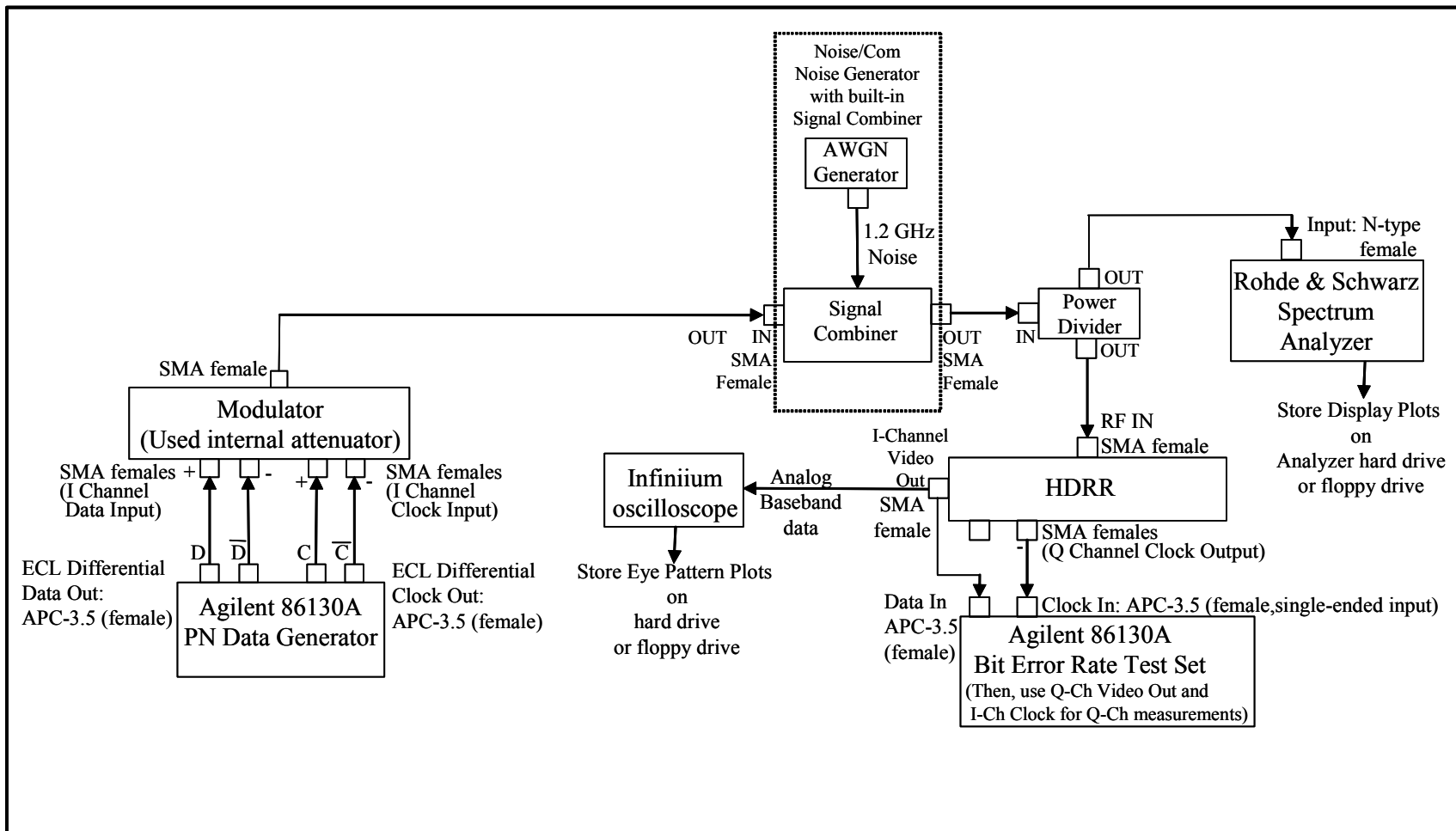


Figure 6-4. Back-To-Back Loop Test Configuration (600 Mbps)

Table 6-1. Back-To-Back 50 Mbps - 600 Mbps Test Unit Settings/Configurations

Unit Name	50 Mbps Unit Settings/Configurations	300 Mbps Unit Settings/Configurations	450 Mbps Unit Settings/Configurations	600 Mbps Unit Settings/Configurations
PN Data Generator	50 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$	300 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$	450 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$	600 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$
Modulator	50 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format	300 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format	450 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format	600 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format
Variable attenuators	C/No varied by increasing attenuation which varied signal level	C/No varied by increasing attenuation which varied signal level	C/No varied by increasing attenuation which varied signal level	C/No varied by increasing attenuation which varied signal level
Noise/Com Noise Generator	1.2 GHz broadband noise Attenuation = 21 dB	1.2 GHz broadband noise Attenuation = 20 dB	1.2 GHz broadband noise Attenuation = 20 dB	1.2 GHz broadband noise Attenuation = 21 dB
Test Receiver	25 Mbps on each Channel Single-Ended ECL output QPSK NRZ-L Data Format	150 Mbps on each Channel Single-Ended ECL output QPSK NRZ-L Data Format	225 Mbps on each Channel Single-Ended ECL output QPSK NRZ-L Data Format	300 Mbps on each Channel Clock: Single-Ended ECL Data: Pre-Bit Sync Signal QPSK NRZ-L Data Format
Bit Error Rate Test Set	25 Mbps (Measured I&Q receiver channels separately) Single-Ended ECL input NRZ-L Data Format PRBS of $2^{23}-1$	150 Mbps (Measured I&Q receiver channels separately) Single-Ended ECL input NRZ-L Data Format PRBS of $2^{23}-1$	225 Mbps (Measured I&Q receiver channels separately) Single-Ended ECL input NRZ-L Data Format PRBS of $2^{23}-1$	300 Mbps (Measured I&Q receiver channels separately) Single-Ended input NRZ-L Data Format PRBS of $2^{23}-1$ (Used Bit sync function)
Spectrum Analyzer	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz

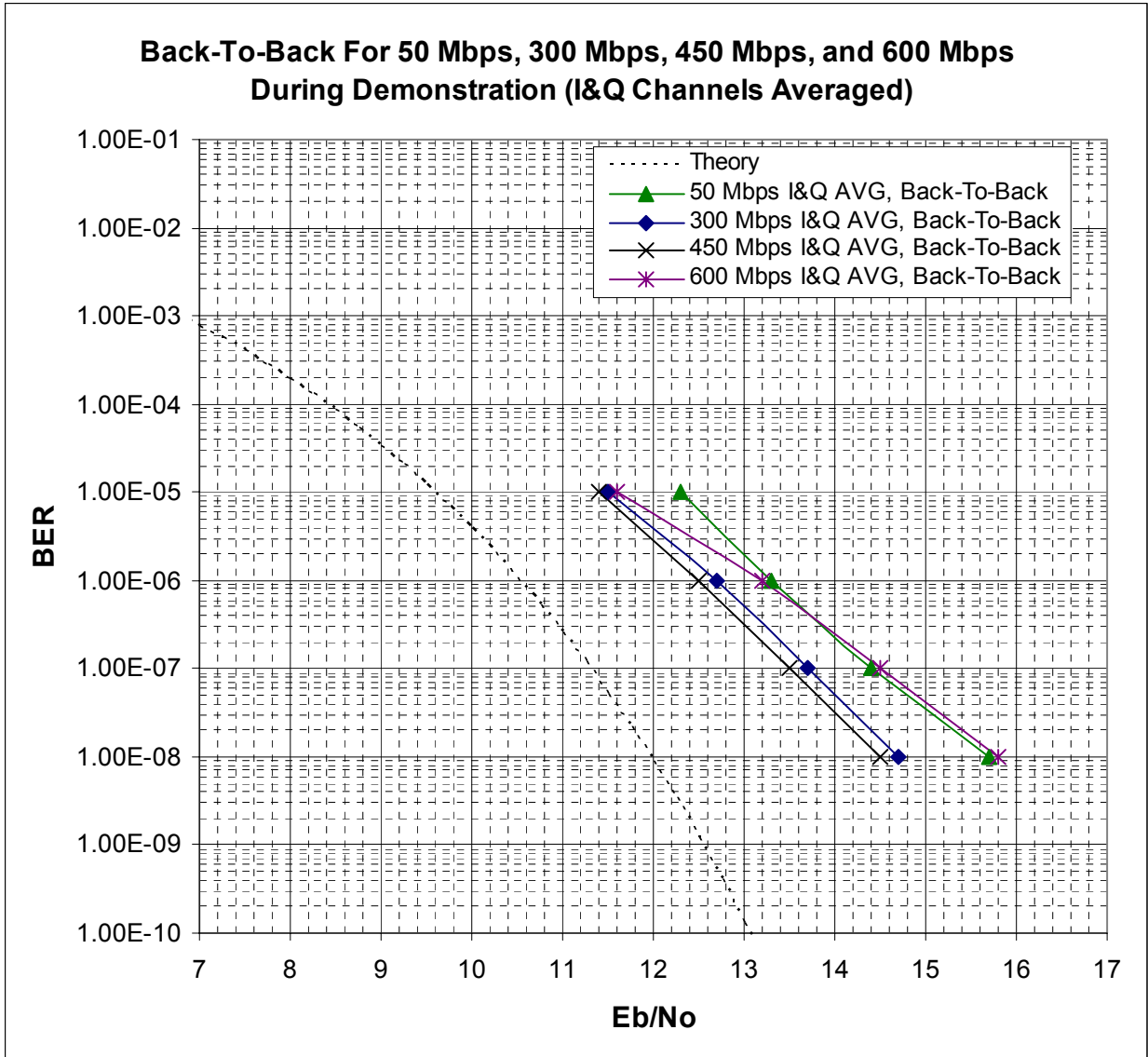
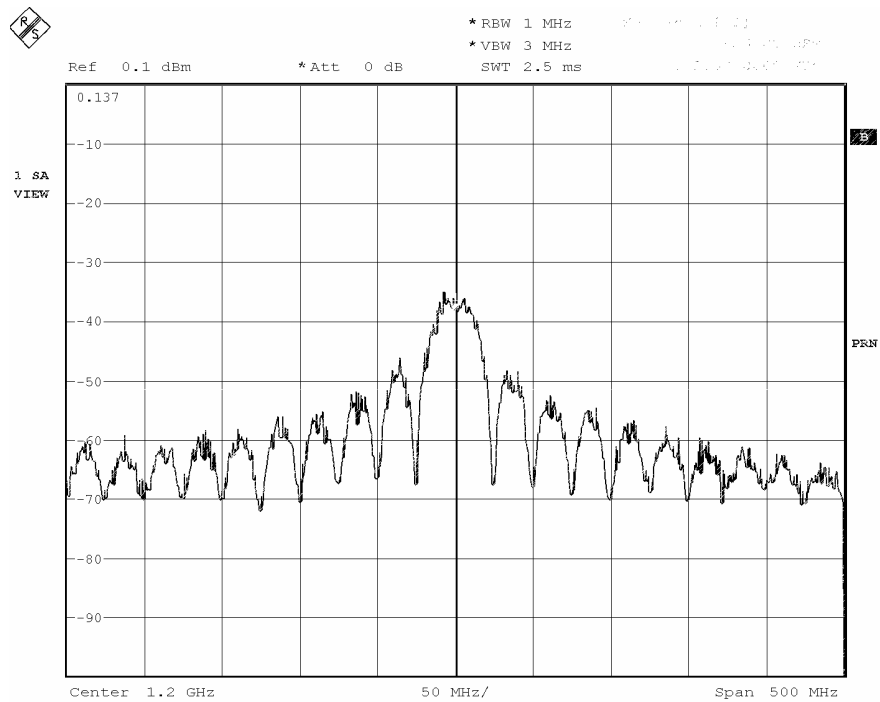


Figure 6-5. Back-To-Back 50 Mbps - 600 Mbps E_b/N_0 Results

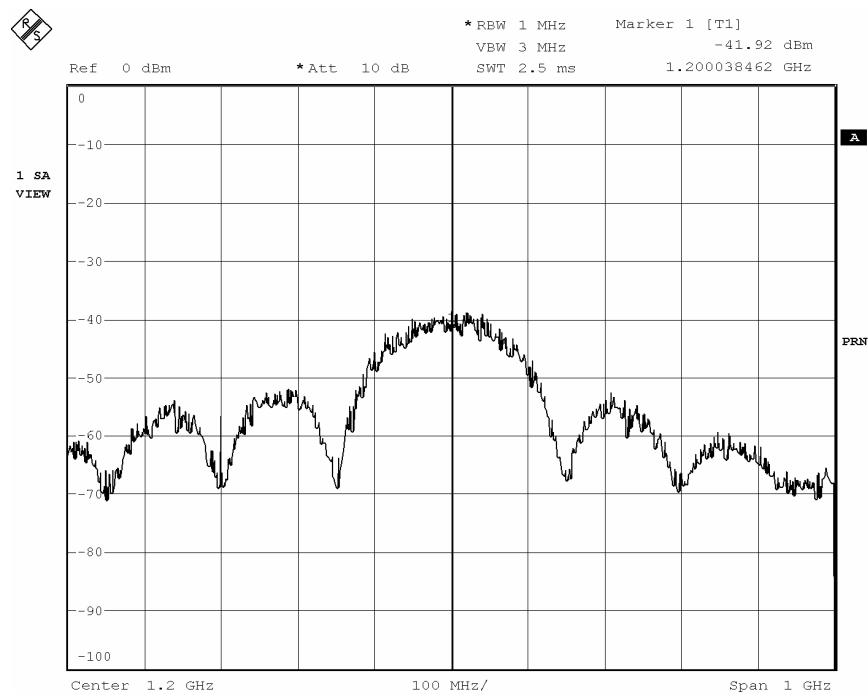
Table 6-2. Back-To-Back 50 Mbps - 600 Mbps Implementation Loss Results

Data Rate	BER	Implementation Loss
50 Mbps	10^{-5}	2.7 dB
	10^{-7}	3.1 dB
300 Mbps	10^{-5}	1.9 dB
	10^{-7}	2.4 dB
450 Mbps	10^{-5}	1.8 dB
	10^{-7}	2.2 dB
600 Mbps	10^{-5}	2.0 dB
	10^{-7}	3.2 dB



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Figure 6-6. Spectrum Analyzer Plot, Back-To-Back, 50 Mbps



Comment A: NO INPUT CONNECTED TO SDR

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Figure 6-7. Spectrum Analyzer Plot, Back-To-Back, 300 Mbps

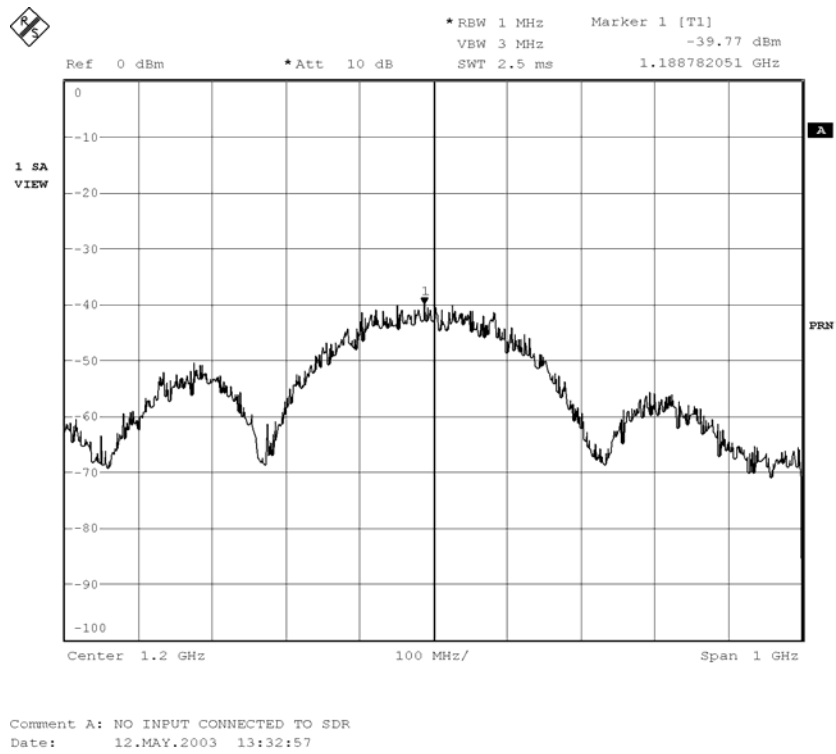


Figure 6-8. Spectrum Analyzer Plot, Back-To-Back, 450 Mbps

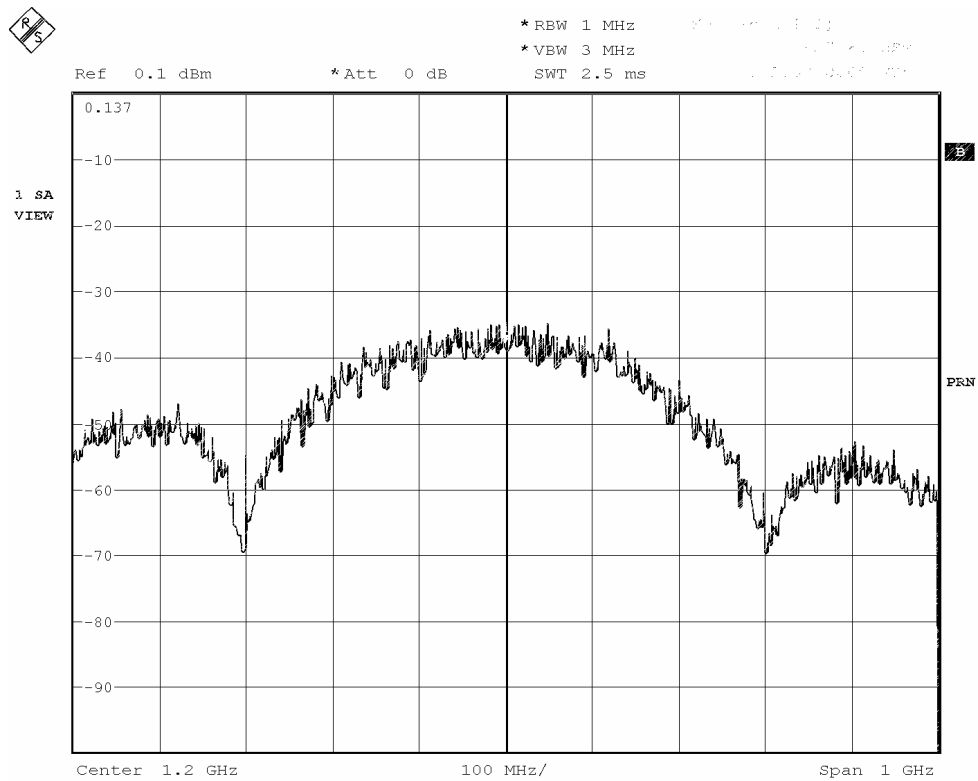


Figure 6-9. Spectrum Analyzer Plot, Back-To-Back, 600 Mbps

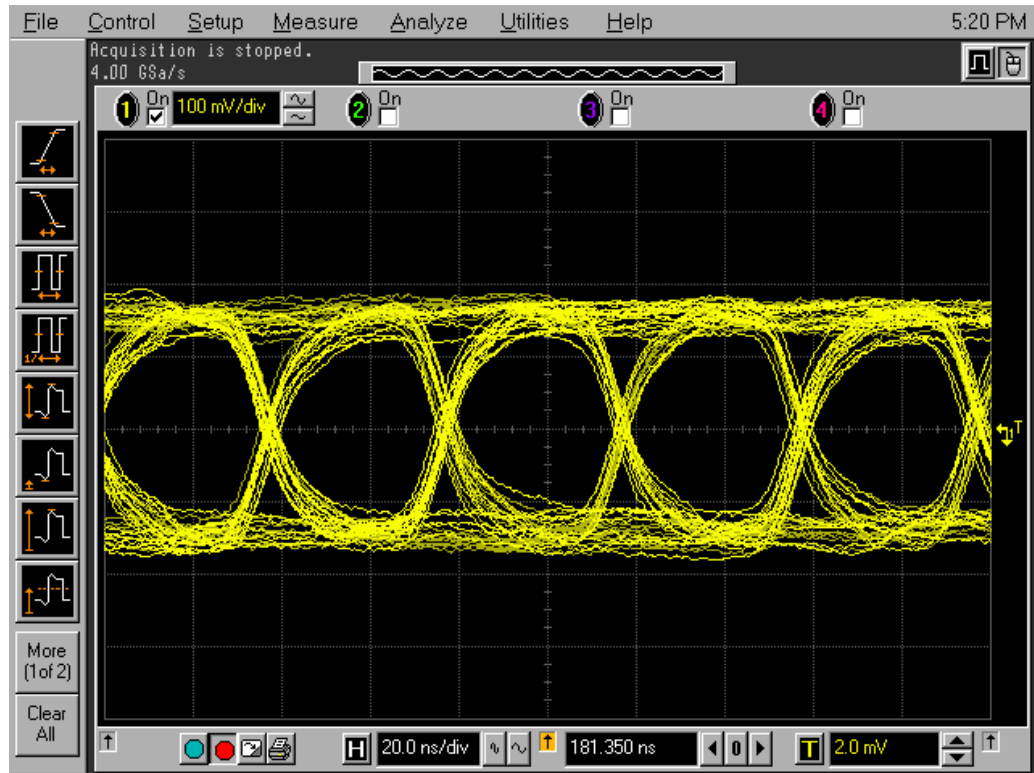


Figure 6-10. Eye Pattern Plot, Back-To-Back, 50 Mbps

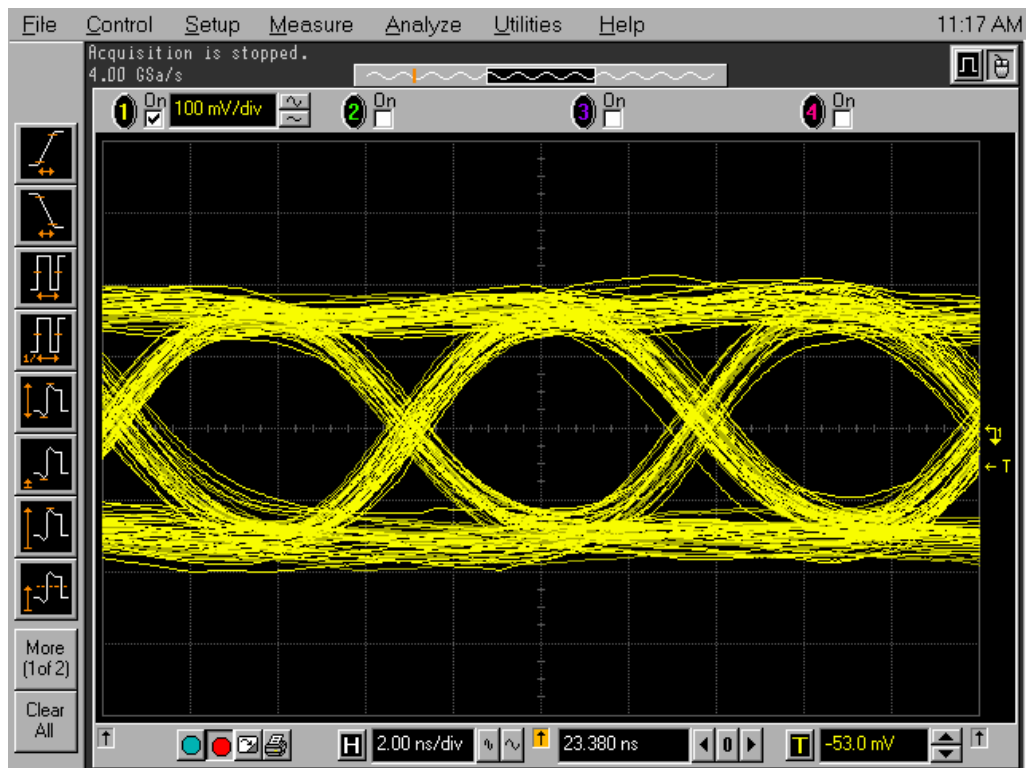


Figure 6-11. Eye Pattern Plot, Back-To-Back, 300 Mbps

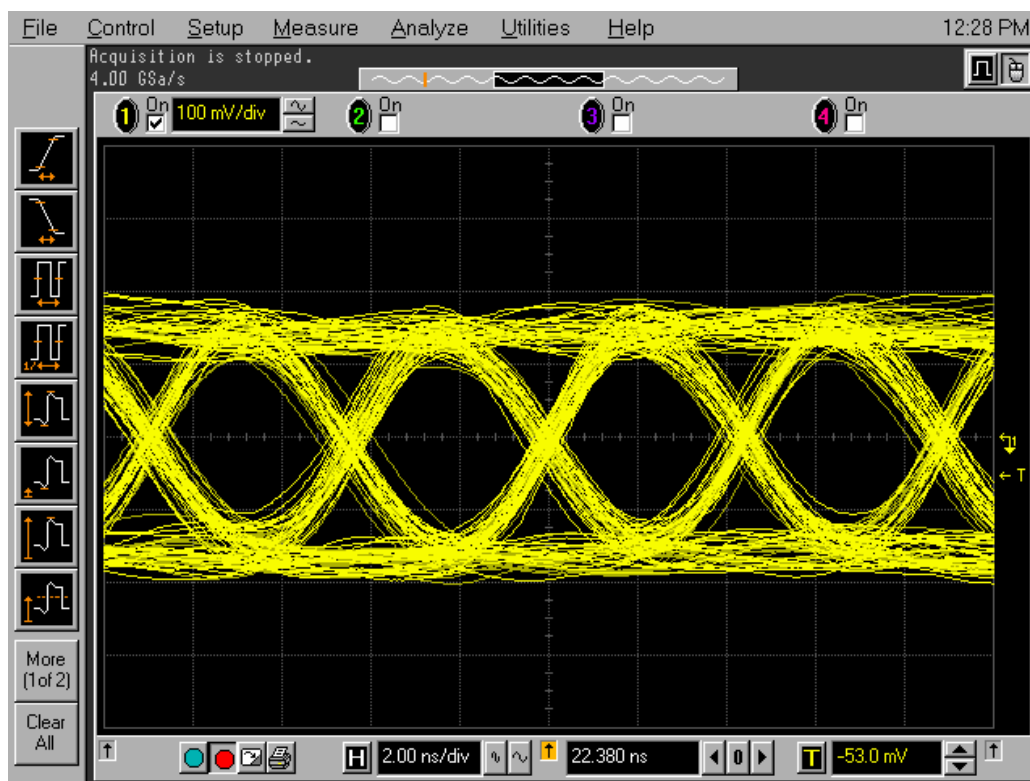


Figure 6-12. Eye Pattern Plot, Back-To-Back, 450 Mbps

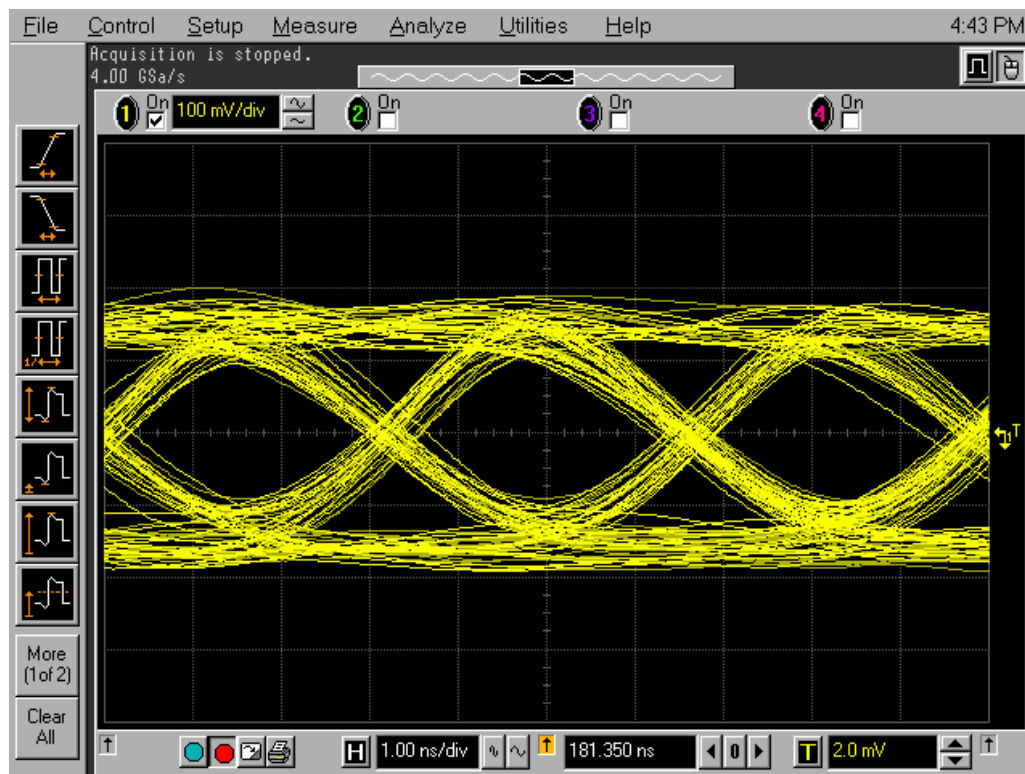


Figure 6-13. Eye Pattern Plot, Back-To-Back, 600 Mbps

6.3 Medium Loop Tests

This section describes the detailed results of the medium loop tests at 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps. Figure 6-14 depicts the detailed medium loop test configuration for the 50 Mbps, 300 Mbps, and 450 Mbps tests. Figure 6-15 depicts the detailed medium loop test configuration for the 600 Mbps tests. For the 600 Mbps tests, the test receiver bit synchronizer was bypassed. For 600 Mbps, the test receiver did not work well when using its bit synchronizer. Therefore, the test team used the bit synchronizer function in the Agilent BERTS to conduct the bit synchronizer function. The 50 Mbps and 600 Mbps tests were conducted at WFF in October 2003. The 300 Mbps and 450 Mbps tests were conducted at WFF in May 2003.

In addition to the receiver and modulator, this test included the FOTS, Ka-band upconverter, LNA, and Ka-Band downconverter. During the medium loop tests, the KaTP test team measured the E_b/N_0 values for BERs from 10^{-5} to 10^{-8} . The PN data generator provided data and clock signals to the modulator. The signal level at the modulator output was varied with variable attenuators in order to generate different E_b/N_0 values. The spectrum analyzer was used to make C/No measurements. The test team calculated the E_b/N_0 values from the C/No measurement data.

Table 6-3 summarizes the test equipment settings and configurations that were used for the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps tests.

Figure 6-16 depicts the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps E_b/N_0 results for the Medium Loop tests. The I & Q channels were averaged in order to generate the curves in Figure 6-16. Table 6-4 lists the implementation loss results for the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps tests. Implementation loss was obtained by subtracting the theoretical curve from the actual measured curve.

Figures 6-17 to 6-20 depict the spectrum analyzer plots for the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps Medium Loop tests. Figures 6-21 to 6-24 depict the eye pattern plots for 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps. The eye pattern data was taken at the output of the receiver matched filter (video output port of receiver).

The 50 Mbps eye pattern shows a signal with the same slightly excessive distortion characteristics that existed during the Back-To-Back tests. Also, the implementation loss between the Back-To-Back 50 Mbps test and Medium Loop 50 Mbps test is not very different. Therefore, it appears that most of the signal distortions in the Medium Loop eye pattern were produced by the receiver, not the Ka-band ground terminal equipment.

Also, during the medium loop tests, the antenna was put in motion. The test data showed that the antenna motor system does not degrade the BER performance.

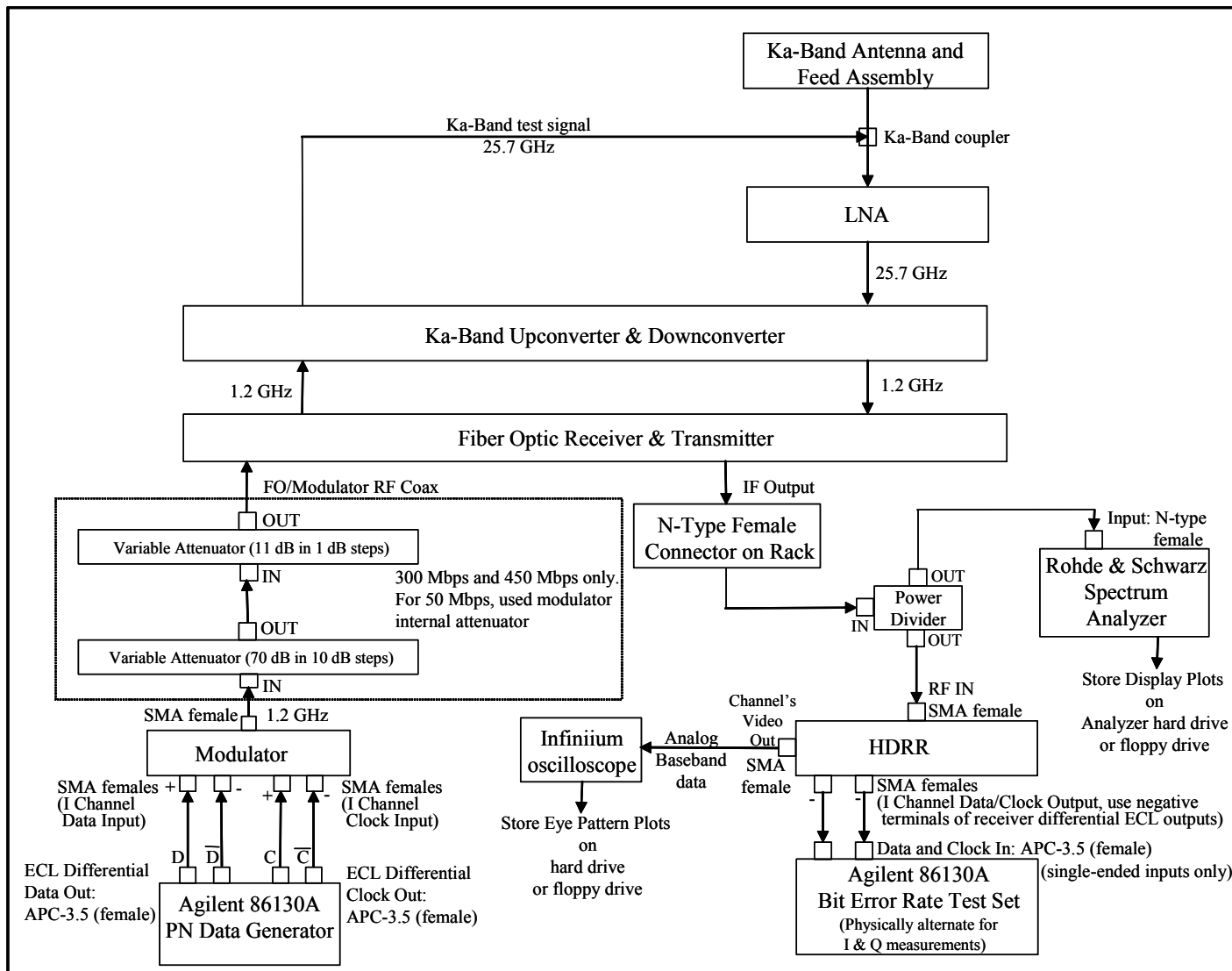


Figure 6-14. Medium Loop Test Configuration (50 Mbps, 300 Mbps, and 450 Mbps)

Table 6-3. Medium Loop 50 Mbps - 600 Mbps Test Unit Settings/Configurations

Unit Name	50 Mbps Unit Settings/Configurations	300 Mbps Unit Settings/Configurations	450 Mbps Unit Settings/Configurations	600 Mbps Unit Settings/Configurations
PN Data Generator	50 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$	300 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$	450 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$	600 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$
Modulator	50 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format	300 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format	450 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format	600 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format
Variable attenuators	C/No varied by increasing attenuation which varied signal level	C/No varied by increasing attenuation which varied signal level	C/No varied by increasing attenuation which varied signal level	C/No varied by increasing attenuation which varied signal level
Test Receiver	25 Mbps on each Channel Single-Ended ECL output QPSK NRZ-L Data Format	150 Mbps on each Channel Single-Ended ECL output QPSK NRZ-L Data Format	225 Mbps on each Channel Single-Ended ECL output QPSK NRZ-L Data Format	300 Mbps on each Channel Clock: Single-Ended ECL Data: Pre-Bit Sync Signal QPSK NRZ-L Data Format
Bit Error Rate Test Set	25 Mbps (Measured I&Q receiver channels separately) Single-Ended ECL input NRZ-L Data Format PRBS of $2^{23}-1$	150 Mbps (Measured I&Q receiver channels separately) Single-Ended ECL input NRZ-L Data Format PRBS of $2^{23}-1$	225 Mbps (Measured I&Q receiver channels separately) Single-Ended ECL input NRZ-L Data Format PRBS of $2^{23}-1$	300 Mbps (Measured I&Q receiver channels separately) Single-Ended input NRZ-L Data Format PRBS of $2^{23}-1$ (Used Bit sync function)
Spectrum Analyzer	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz

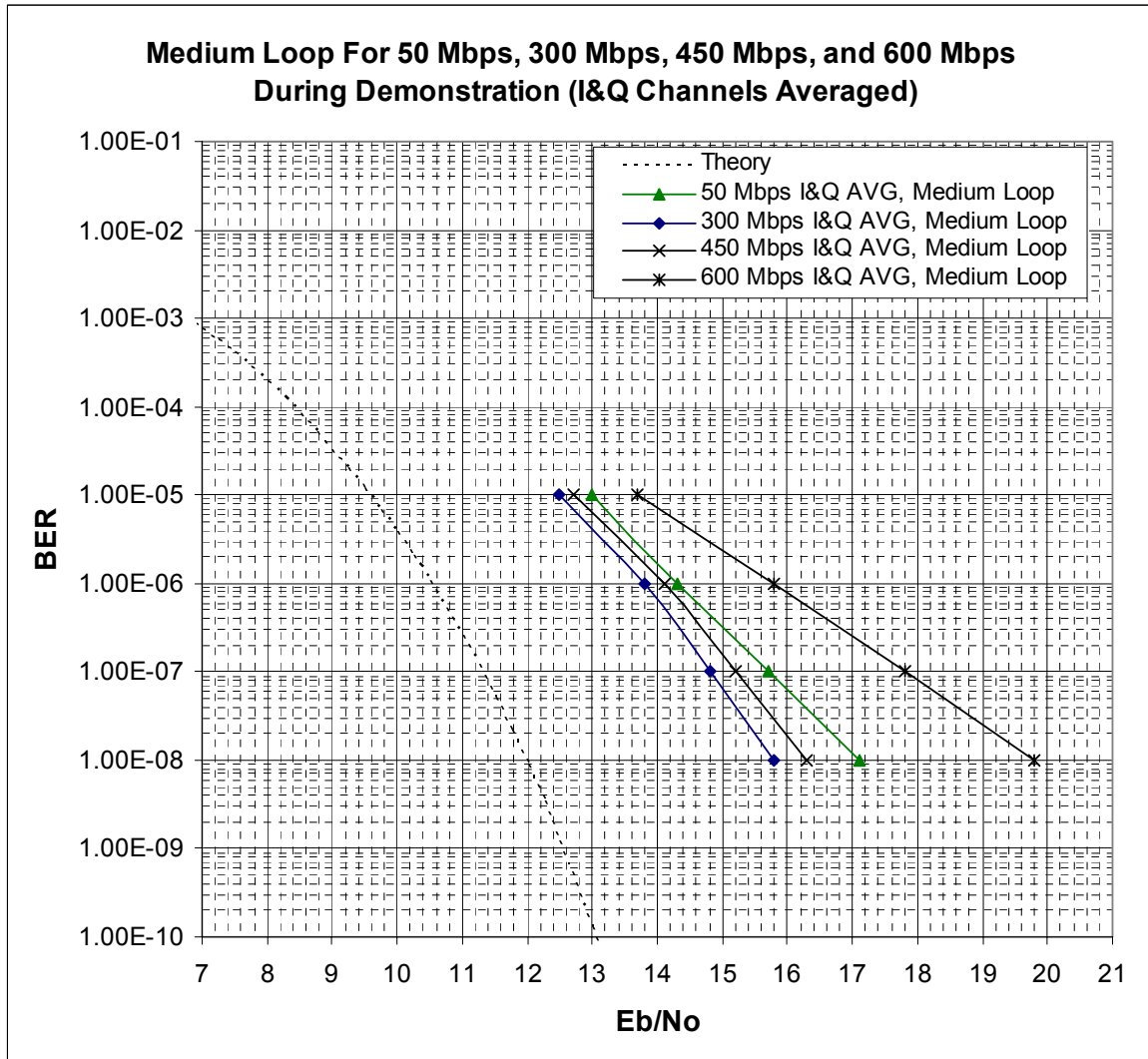
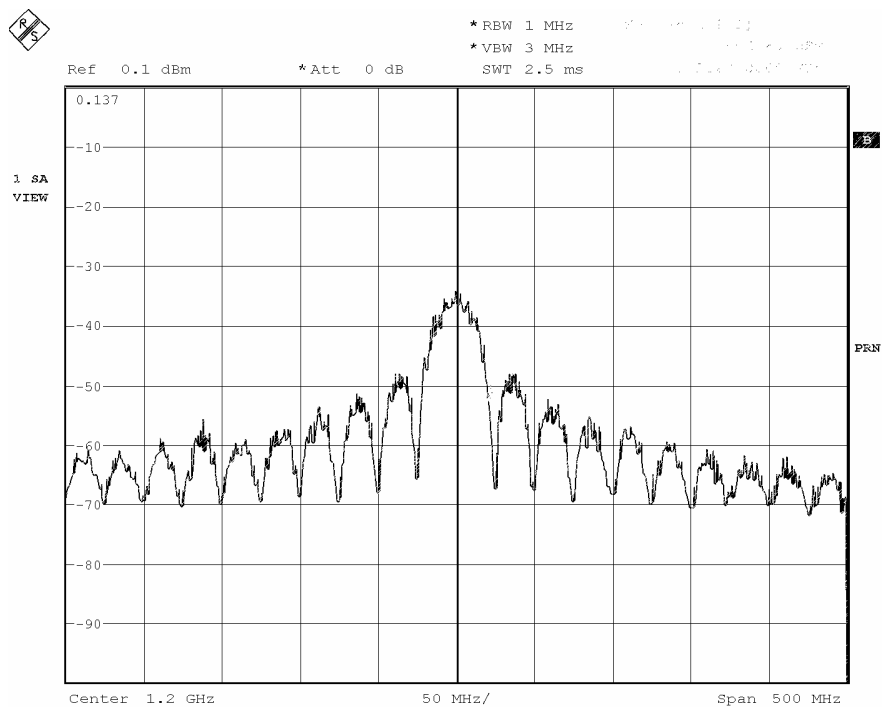


Figure 6-16. Medium Loop 50 Mbps - 600 Mbps E_b/N_0 Results

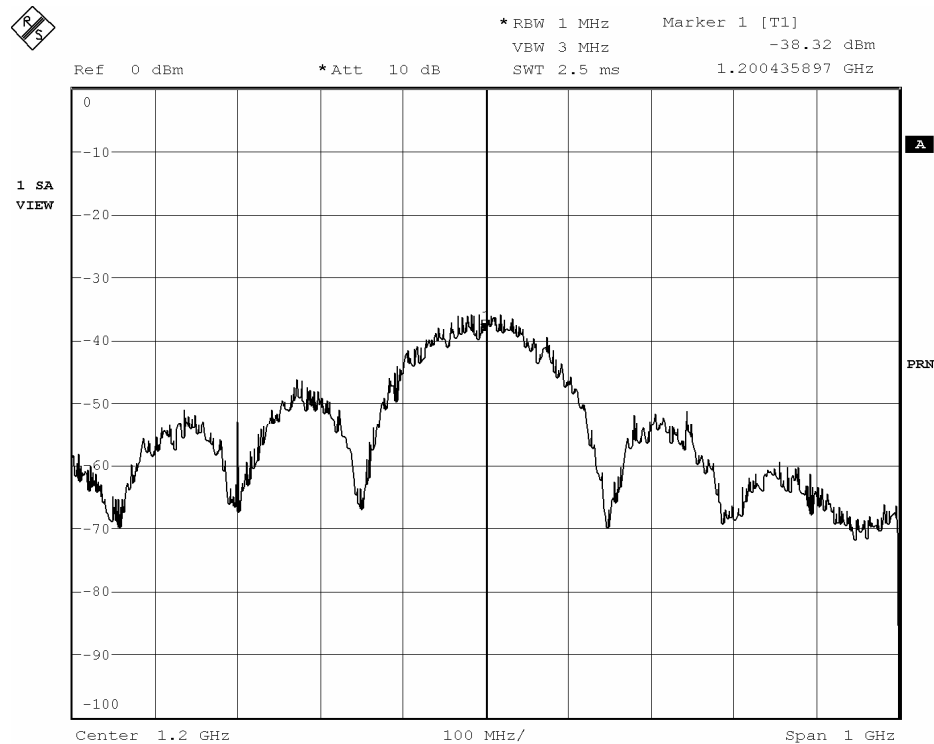
Table 6-4. Medium Loop 50 Mbps - 600 Mbps Implementation Loss Results

Data Rate	BER	Implementation Loss
50 Mbps	10^{-5}	3.4 dB
	10^{-7}	4.4 dB
300 Mbps	10^{-5}	2.9 dB
	10^{-7}	3.5 dB
450 Mbps	10^{-5}	3.1 dB
	10^{-7}	3.9 dB
600 Mbps	10^{-5}	4.1 dB
	10^{-7}	6.5 dB



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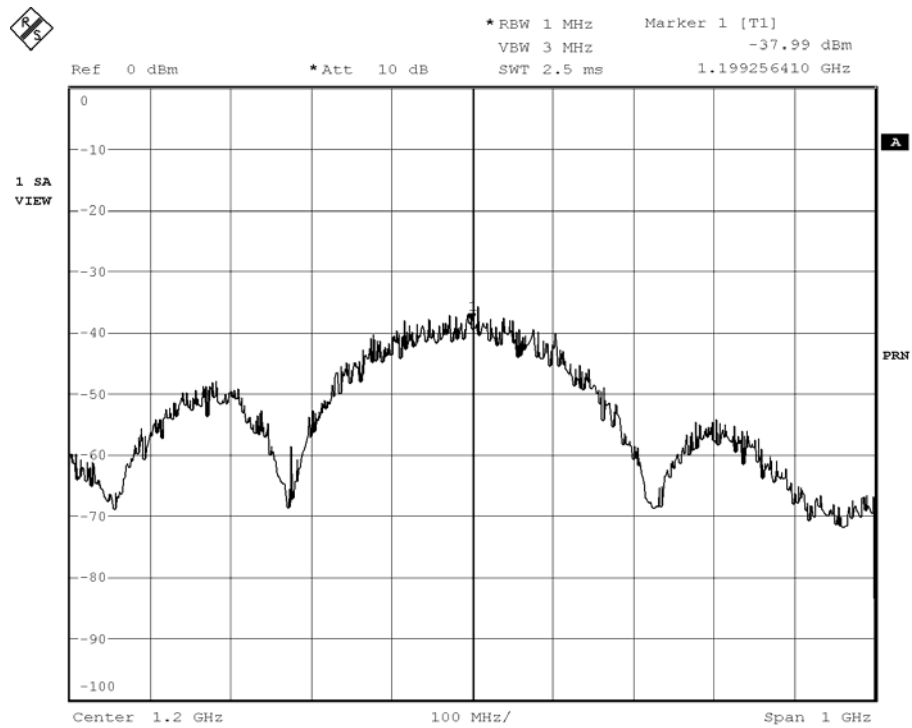
Figure 6-17. Spectrum Analyzer Plot, Medium Loop, 50 Mbps



Comment A: NO INPUT CONNECTED TO SDR

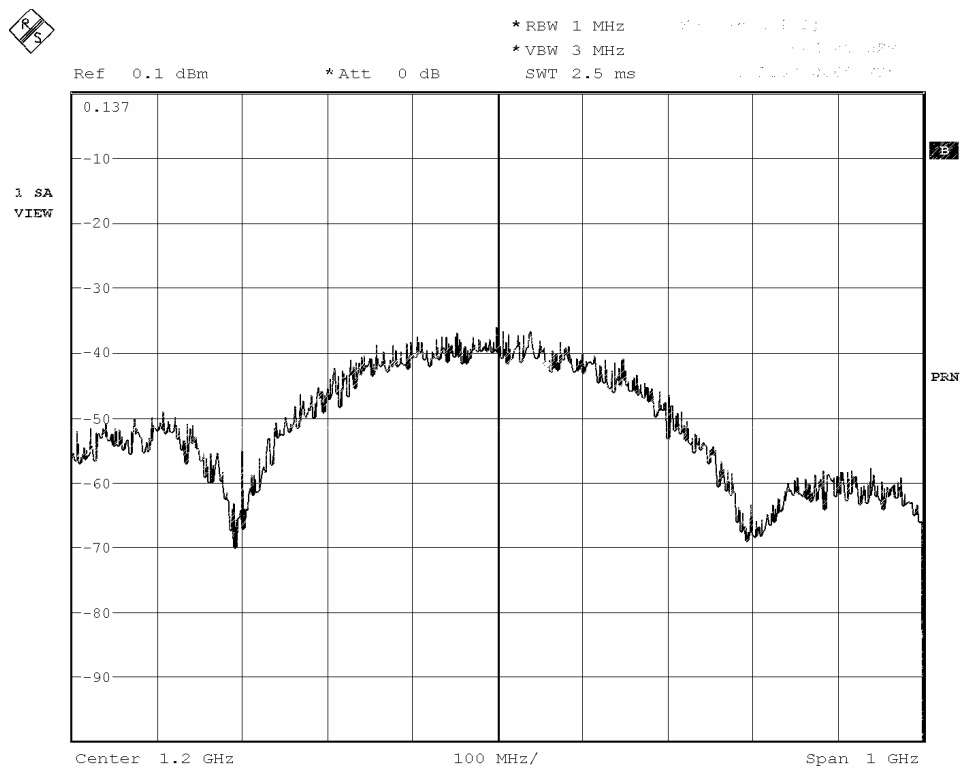
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Figure 6-18. Spectrum Analyzer Plot, Medium Loop, 300 Mbps



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Date: 13.MAY.2003 10:39:54

Figure 6-19. Spectrum Analyzer Plot, Medium Loop, 450 Mbps



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Figure 6-20. Spectrum Analyzer Plot, Medium Loop, 600 Mbps

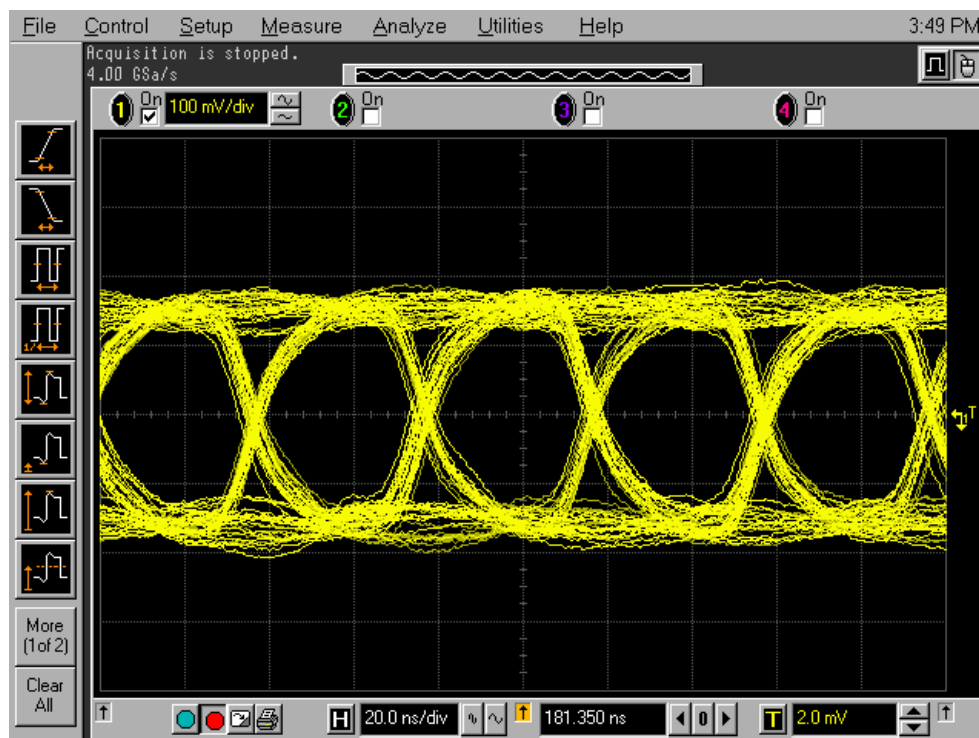


Figure 6-21. Eye Pattern Plot, Medium Loop, 50 Mbps

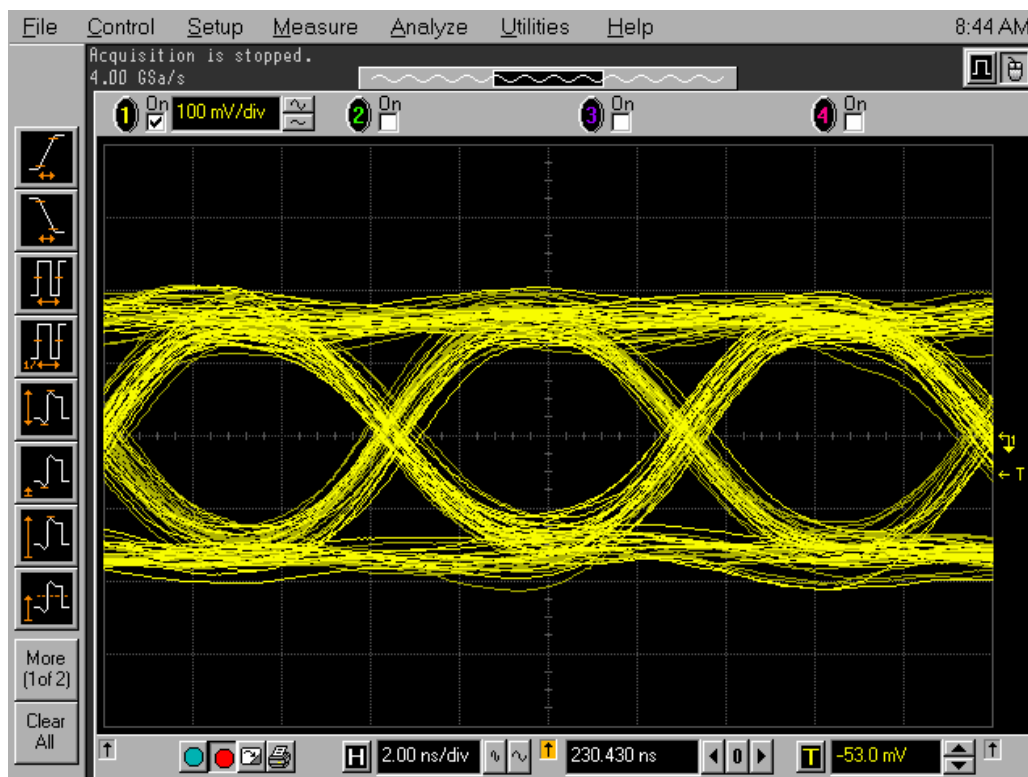


Figure 6-22. Eye Pattern Plot, Medium Loop, 300 Mbps

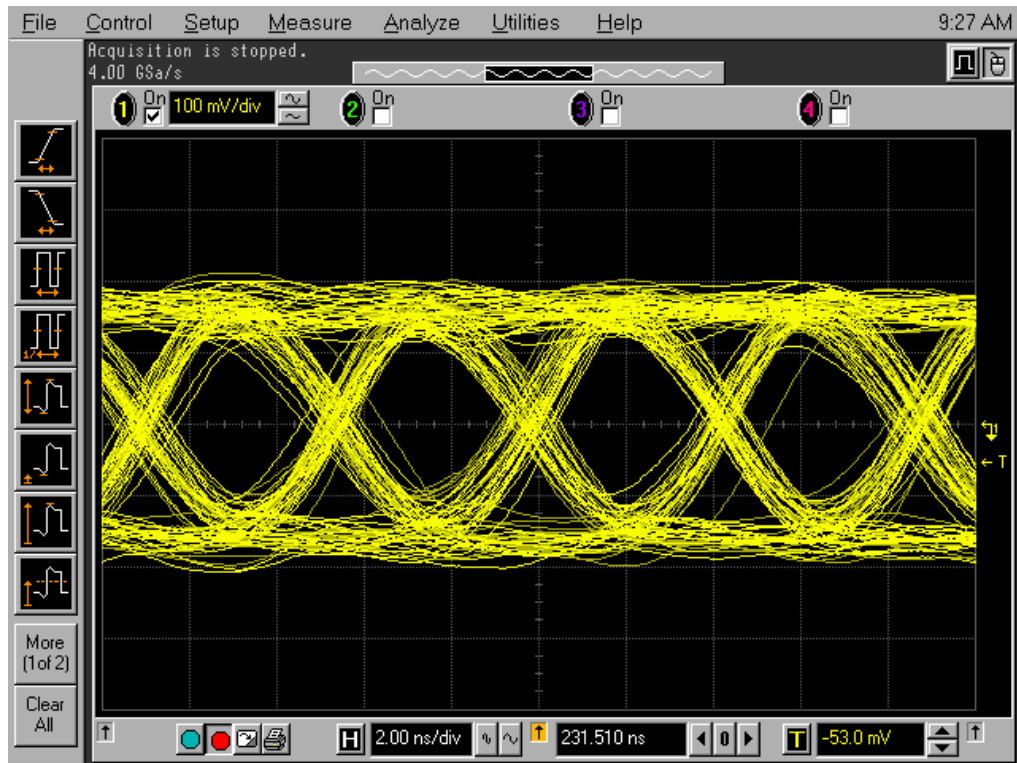


Figure 6-23. Eye Pattern Plot, Medium Loop, 450 Mbps

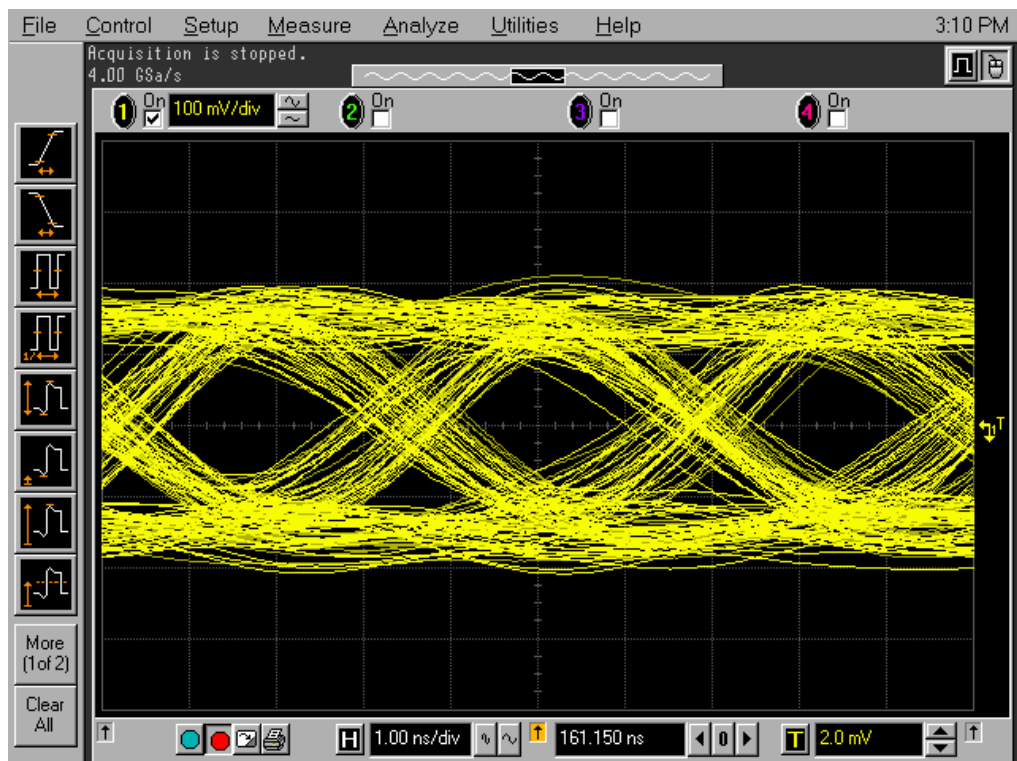


Figure 6-24. Eye Pattern Plot, Medium Loop, 600 Mbps

6.4 End-To-End Loop Tests

This section describes the detailed results of the end-to-end loop tests with the boresite tower at 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps. Figure 6-25 depicts the detailed end-to-end test configuration for the 50 Mbps, 300 Mbps, and 450 Mbps tests. Figure 6-26 depicts the detailed end-to-end test configuration for the 600 Mbps tests. For the 600 Mbps tests, the test receiver bit synchronizer was bypassed. For 600 Mbps, the test receiver did not work well when using its bit synchronizer. Therefore, the test team used the bit synchronizer function in the Agilent BERTS to conduct the bit synchronizer function. The 50 Mbps and 600 Mbps tests were conducted at WFF in October 2003. The 300 Mbps and 450 Mbps tests were conducted at WFF in May 2003.

This test included the ground terminal antenna and antenna feed prior to the LNA. It also included the test transmitter equipment at the bore-site tower.

During the end-to-end tests, the KaTP test team measured the E_b/N_0 values for BERs from 10^{-5} to 10^{-8} . The PN data generator provided data and clock signals to the modulator. The signal level at the modulator output was varied by using the internal variable attenuator of the modulator in order to generate different E_b/N_0 values. The spectrum analyzer was used to make C/No measurements. The test team calculated the E_b/N_0 values from the C/No measurement data.

Table 6-5 summarizes the test equipment settings and configurations that were used for the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps tests.

Figure 6-27 depicts the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps E_b/N_0 results for the end-to-end loop tests. The I & Q channels were averaged in order to generate the curves in Figure 6-27. Table 6-6 lists the implementation loss results for the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps tests. Implementation loss was obtained by subtracting the theoretical curve from the actual measured curve.

Figures 6-28 to 6-31 depict the spectrum analyzer plots for the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps end-to-end loop tests. Figures 6-32 to 6-35 depict the eye pattern plots for 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps. The eye pattern data was taken at the output of the receiver matched filter (video output port of receiver).

The 50 Mbps eye pattern shows a signal with the same slightly excessive distortion characteristics that existed during the Back-To-Back tests. Also, the implementation loss between the Back-To-Back 50 Mbps test and End-To-End 50 Mbps test is not very different. Therefore, it appears that most of the signal distortions in the End-To-End eye pattern were produced by the receiver, not the Ka-band ground terminal equipment.

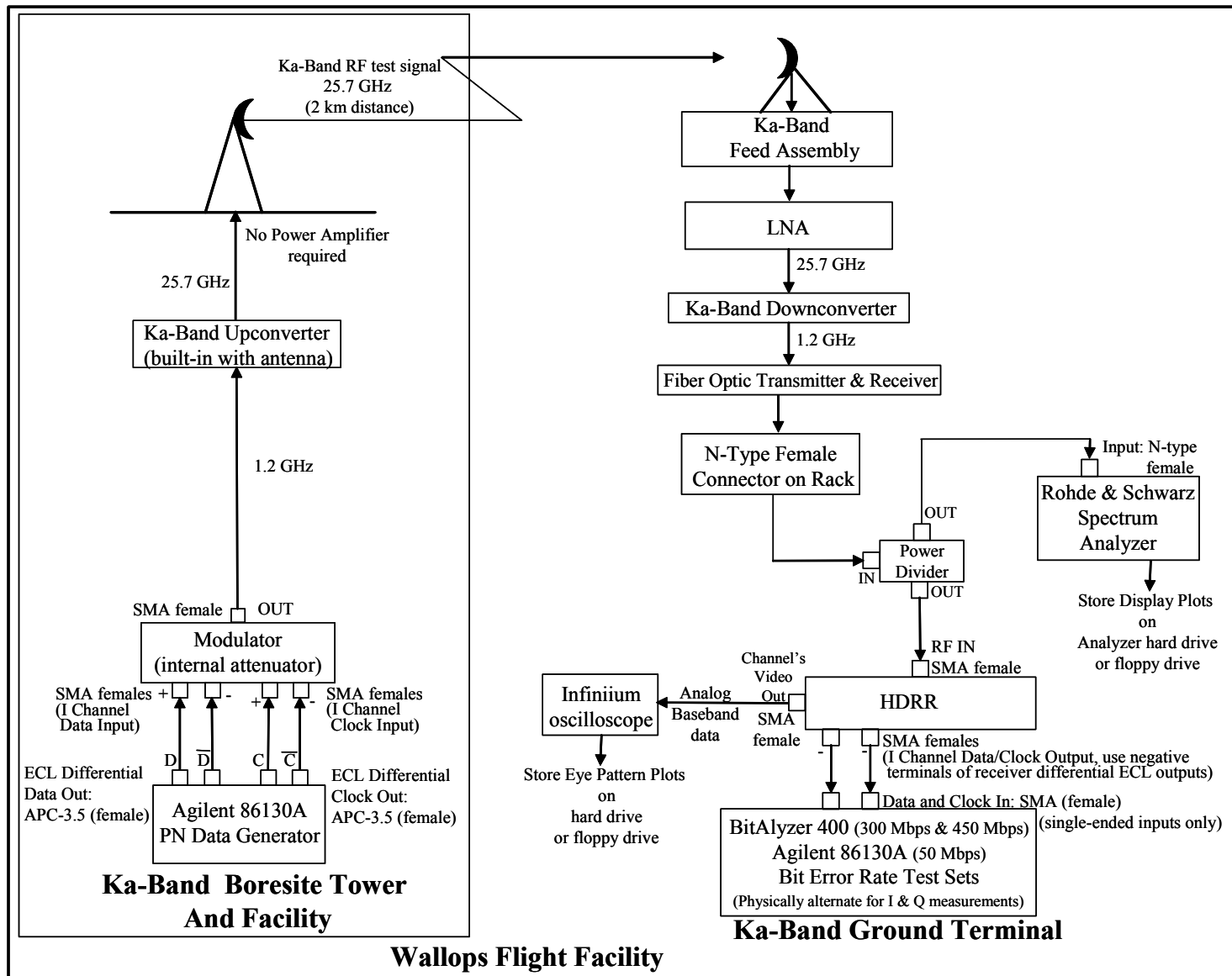


Figure 6-25. End-To-End Test Configuration (50 Mbps, 300 Mbps, and 450 Mbps)

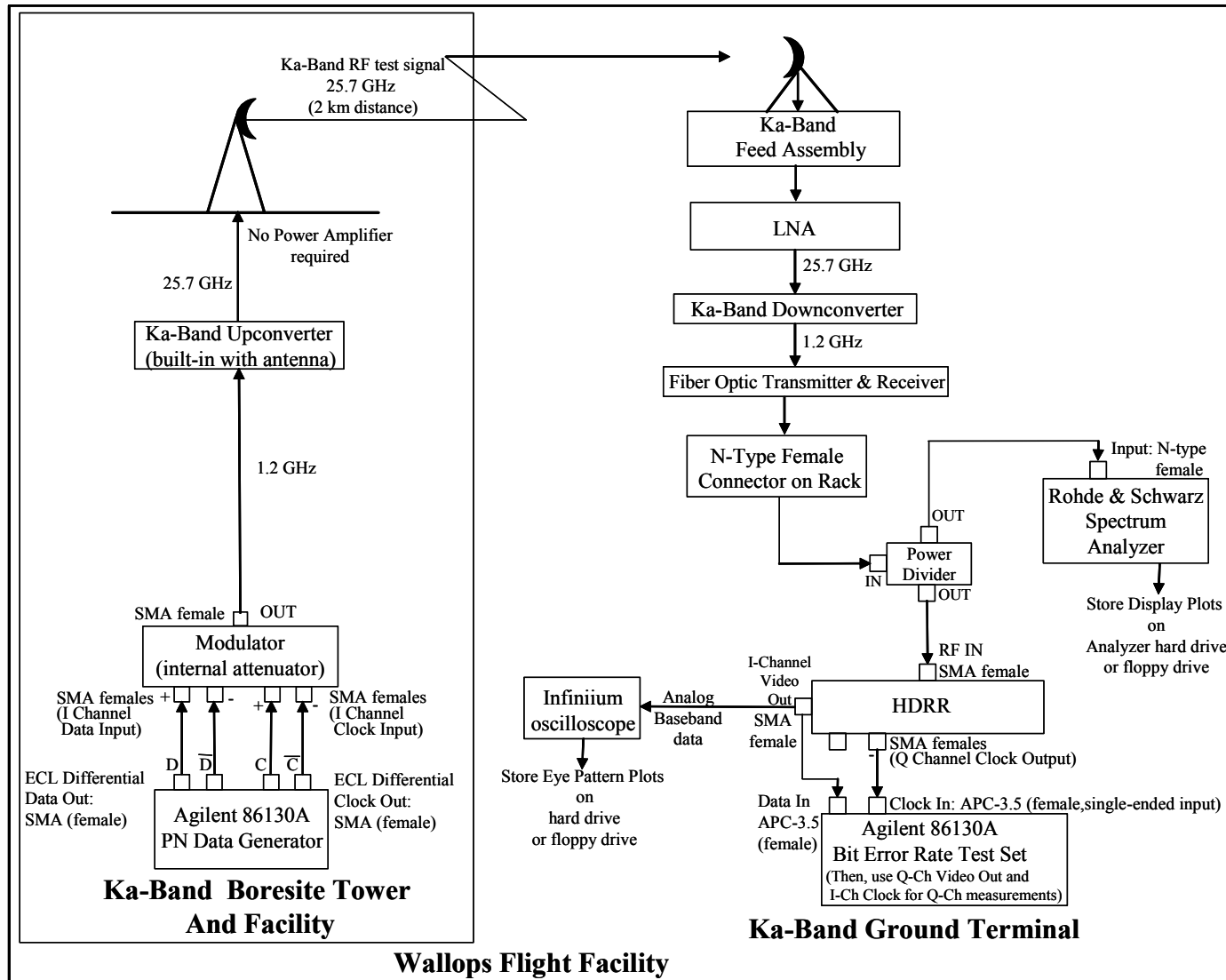


Figure 6-26. End-To-End Test Configuration (600 Mbps)

Table 6-5. End-To-End 50 Mbps - 600 Mbps Test Unit Settings/Configurations

Unit Name	50 Mbps Unit Settings/Configurations	300 Mbps Unit Settings/Configurations	450 Mbps Unit Settings/Configurations	600 Mbps Unit Settings/Configurations
PN Data Generator	50 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$	300 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$	450 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$	600 Mbps Differential ECL output NRZ-L Data Format PRBS of $2^{23}-1$
Modulator	50 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format	300 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format	450 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format	600 Mbps Differential ECL input SQPSK, IF = 1.2 GHz NRZ-L Data Format
Variable attenuators	C/No varied by increasing attenuation which varied signal level	C/No varied by increasing attenuation which varied signal level	C/No varied by increasing attenuation which varied signal level	C/No varied by increasing attenuation which varied signal level
Test Receiver	25 Mbps on each Channel Single-Ended ECL output QPSK NRZ-L Data Format	150 Mbps on each Channel Single-Ended ECL output QPSK NRZ-L Data Format	225 Mbps on each Channel Single-Ended ECL output QPSK NRZ-L Data Format	300 Mbps on each Channel Clock: Single-Ended ECL Data: Pre-Bit Sync Signal QPSK NRZ-L Data Format
Bit Error Rate Test Set	25 Mbps (Measured I&Q receiver channels separately) Single-Ended ECL input NRZ-L Data Format PRBS of $2^{23}-1$	150 Mbps (Measured I&Q receiver channels separately) Single-Ended ECL input NRZ-L Data Format PRBS of $2^{23}-1$	225 Mbps (Measured I&Q receiver channels separately) Single-Ended ECL input NRZ-L Data Format PRBS of $2^{23}-1$	300 Mbps (Measured I&Q receiver channels separately) Single-Ended input NRZ-L Data Format PRBS of $2^{23}-1$ (Used Bit sync function)
Spectrum Analyzer	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz	Center Frequency = 1.2 GHz Resolution BW = 1.0 MHz

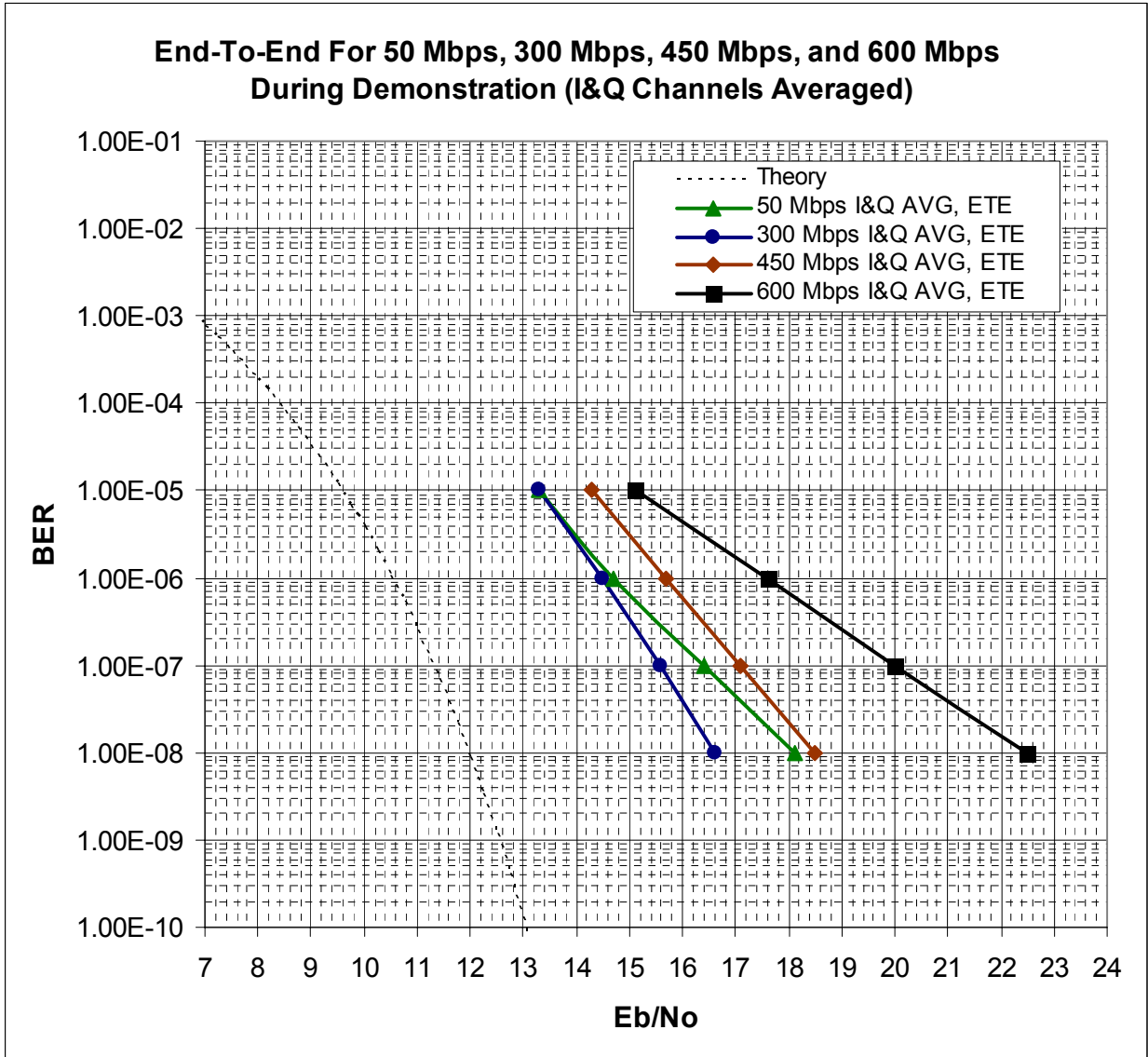
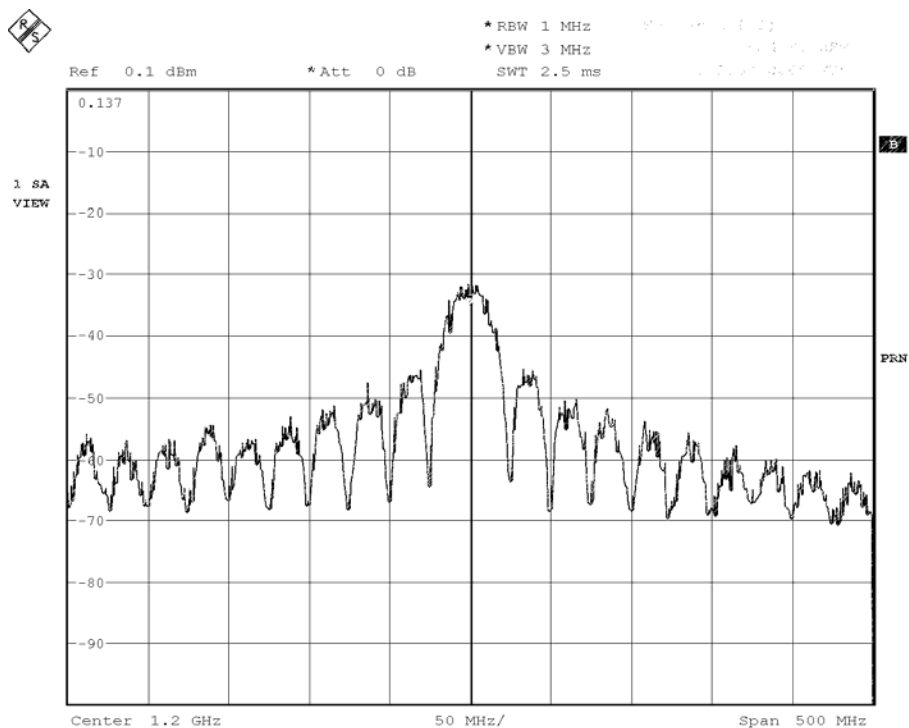


Figure 6-27. End-To-End 50 Mbps - 600 Mbps Eb/No Results

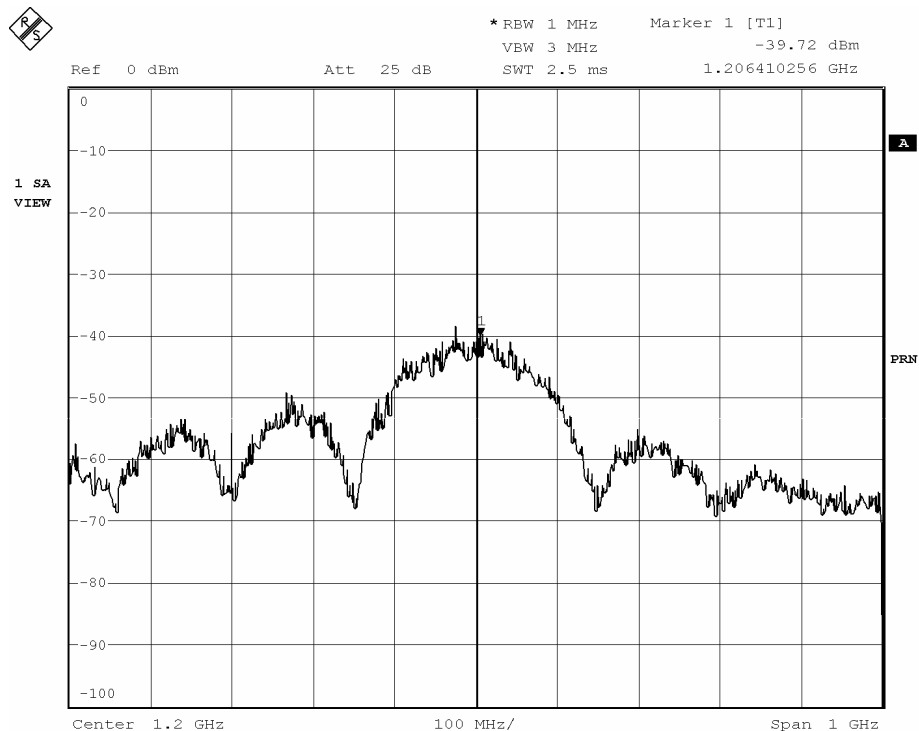
Table 6-6. End-To-End 50 Mbps - 600 Mbps Implementation Loss Results

Data Rate	BER	Implementation Loss
50 Mbps	10^{-5}	3.7 dB
	10^{-7}	5.1 dB
300 Mbps	10^{-5}	3.7 dB
	10^{-7}	4.3 dB
450 Mbps	10^{-5}	4.7 dB
	10^{-7}	5.8 dB
600 Mbps	10^{-5}	5.5 dB
	10^{-7}	8.7 dB



Date: 23.OCT.2003 09:50:55

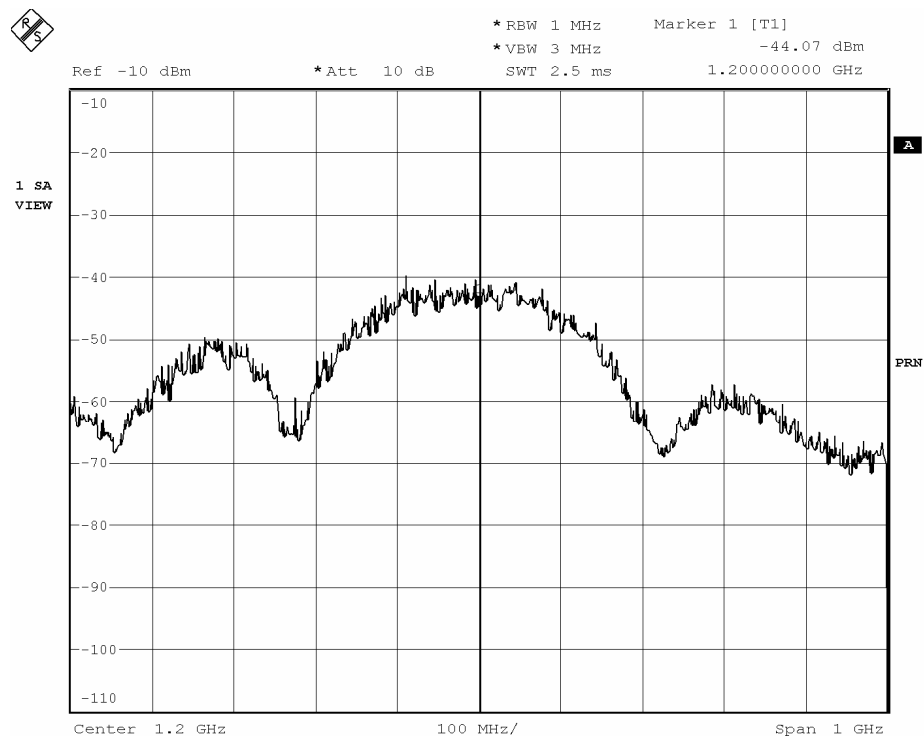
Figure 6-28. Spectrum Analyzer Plot, End-To-End, 50 Mbps



Comment A: NO INPUT CONNECTED TO SDR

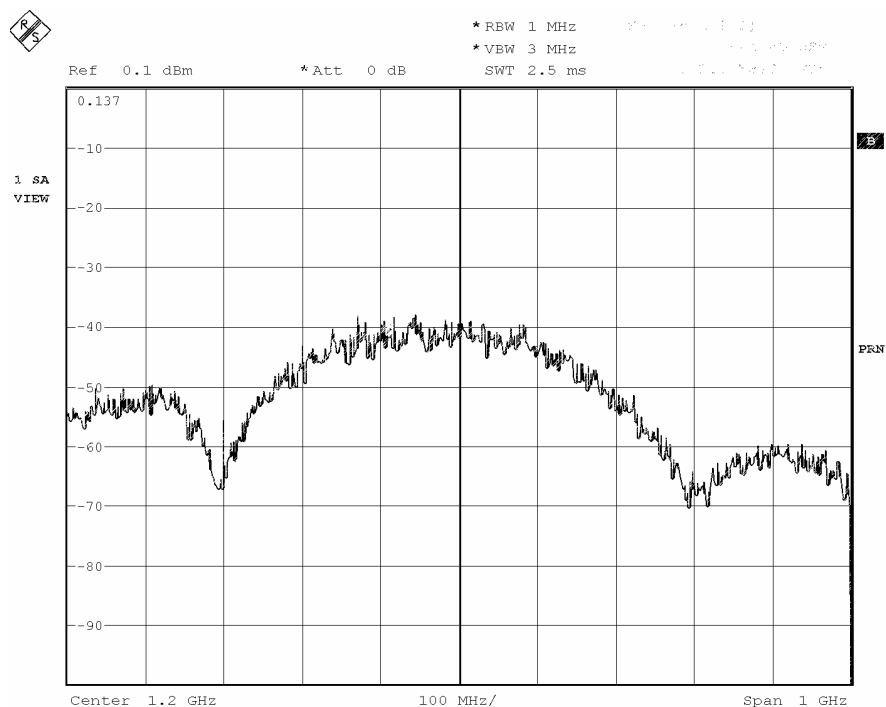
Date: 14.MAY.2003 14:32:02

Figure 6-29. Spectrum Analyzer Plot, End-To-End, 300 Mbps



Comment A: NO INPUT CONNECTED TO SDR
Date: 15.MAY.2003 10:43:33

Figure 6-30. Spectrum Analyzer Plot, End-To-End, 450 Mbps



Date: 22.OCT.2003 13:10:32

Figure 6-31. Spectrum Analyzer Plot, End-To-End, 600 Mbps

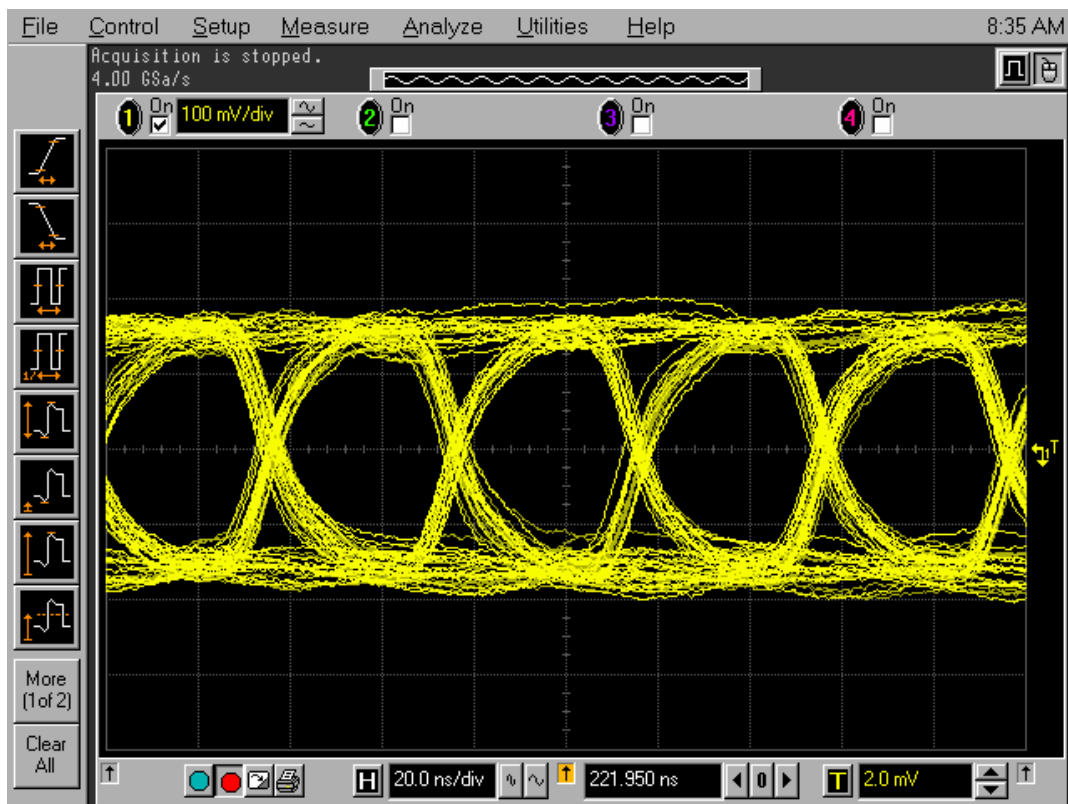


Figure 6-32. Eye Pattern Plot, End-To-End, 50 Mbps

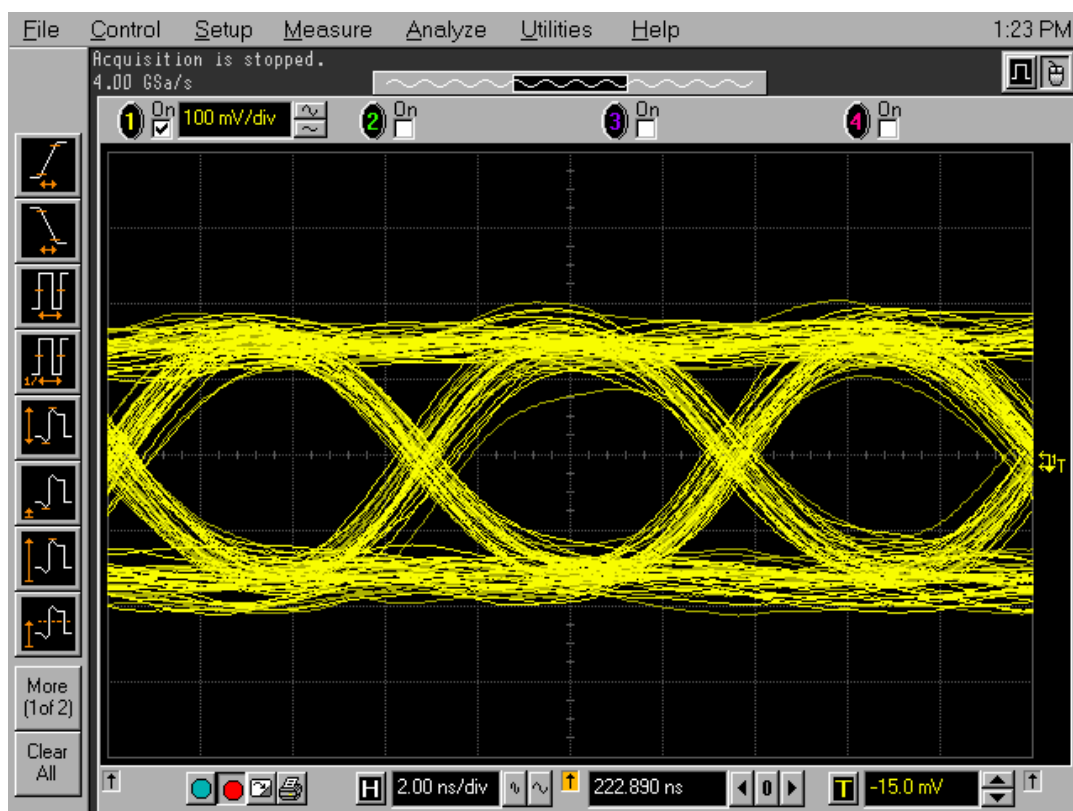


Figure 6-33. Eye Pattern Plot, End-To-End, 300 Mbps

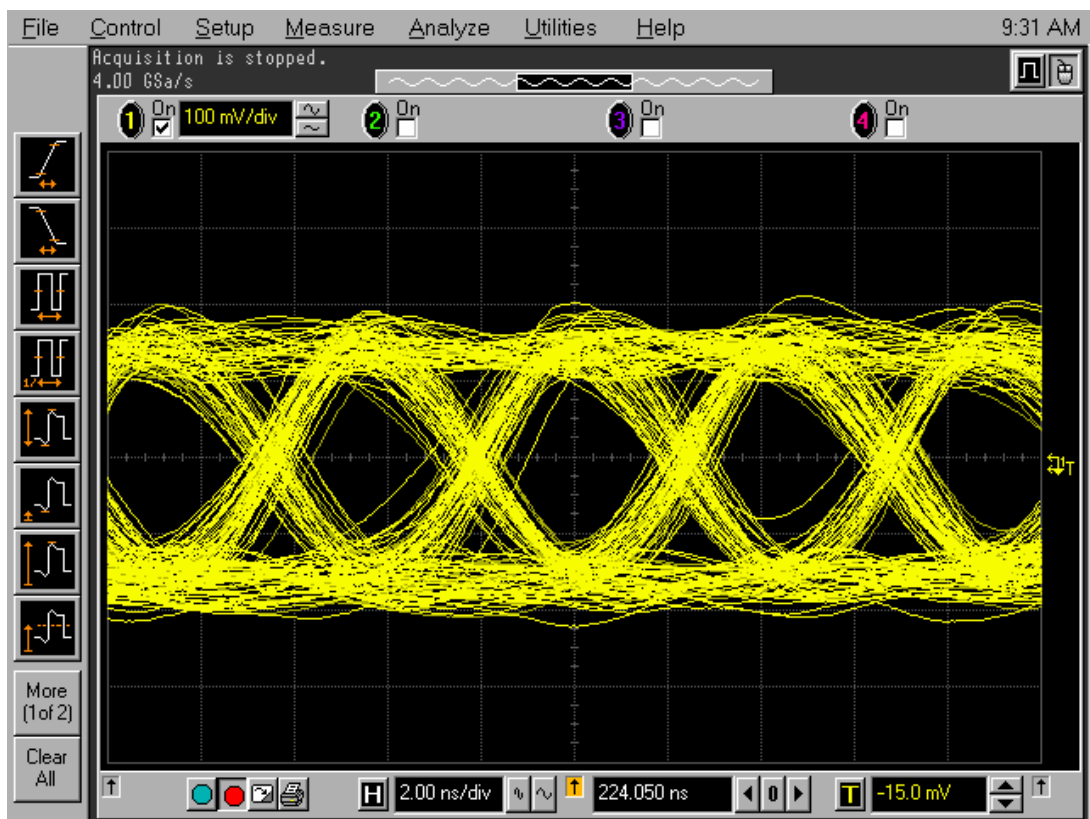


Figure 6-34. Eye Pattern Plot, End-To-End, 450 Mbps

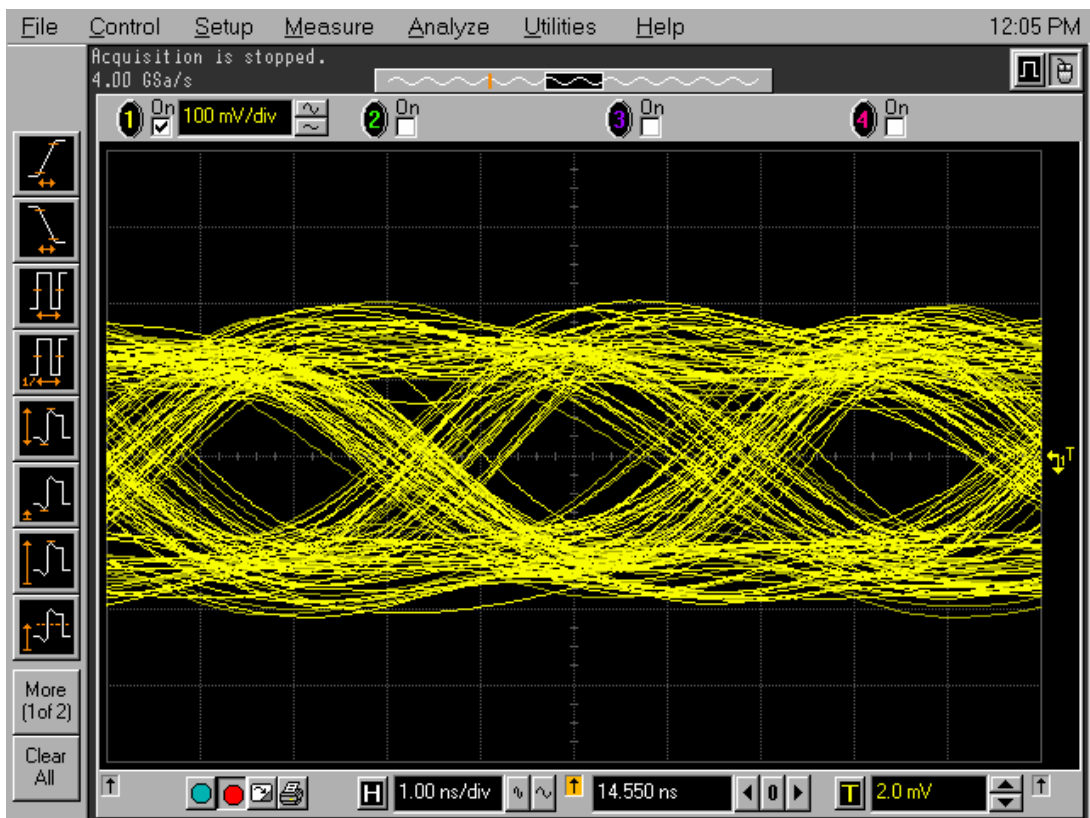


Figure 6-35. Eye Pattern Plot, End-To-End, 600 Mbps

6.5 Summary Of Results

This section summarizes the results from the Back-To-Back Loop tests, Medium Loop tests, and End-To-End Tests. The Ka-Band Ground Terminal can support data rates up to 600 Mbps, but the implementation loss values are higher than desired for an operational link, especially at 600 Mbps. The BER portion of the demonstration provides a baseline for the Ka-Band Ground Terminal performance and shows that the Goddard Space Flight Center (GSFC) can consider using the Ka-Band Ground Terminal as a test-bed to support Ka-Band technology developments like the GSFC High Rate User Ka-Band Phased Array Antenna.

Figure 6-36 depicts the 600 Mbps results for all of the test configurations. As expected, the implementation loss grew as more equipment was added to the test configuration. Table 6-7 lists the 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps implementation loss values.

Also, when a Ka-band orbiting spacecraft becomes available for BER testing at any data rate, the test team recommends that the NASA conduct BER tests with that spacecraft at Ka-band.

The remainder of section 6.5 details the BER and implementation loss performance and provides recommendations for Ka-Band Ground Terminal improvements.

6.5.1 Ka-Band Ground Terminal Implementation Loss Performance

As stated above, the implementation loss performance of the Ka-band Ground Terminal should be improved before it is used in an operation link. The KaTP project understands that a 5.5 dB implementation loss for a 10^{-5} BER at 600 Mbps is higher than desired for an operational GN data service. However, approximately 1.4 dB of the loss can be attributed to the available test transmitter system at the boresite tower. This value was determined through medium loop tests that included all of the significant ground terminal components except for the 5.4 meter antenna, and resulted in an implementation loss of 4.1 dB. Also, medium loop frequency response data showed that the Ka-Band Ground Terminal does have a tilt characteristic in the gain response (non-flat gain response) and a parabolic characteristic in the phase response. The gain tilt characteristic and the parabolic phase characteristic contribute to signal distortions.

Table 6-8 provides the results of the medium loop computer simulations at 600 Mbps that were conducted as part of this project. Measured medium loop frequency response data, a receiver with a 2.0 dB back-to-back implementation loss, a receiver with a 2.5 dB back-to-back implementation loss, and worst-case customer constraint values were used in the simulations. One simulation included a cable equalizer that removed both the gain tilt characteristic and the parabolic phase characteristic. Another simulation included an Adaptive Baseband Equalizer (ABBE) with and without a cable equalizer. However, no coding was used during the simulations. Also, two methods were used to introduce the back-to-back implementation loss in the test receiver: Cross Talk in the receiver and Ripple Gain Flatness/Phase nonlinearity in the receiver.

When using a 2.0 dB back-to-back implementation loss for the test receiver with cross talk, the computer simulations indicated that a 3.36 dB total system implementation loss can be achieved by adding a cable equalizer that removes the gain versus frequency tilt and parabolic phase characteristic that exists in the Ka-band Ground Terminal. The computer simulations indicated

that a 2.79 dB total system implementation loss can be achieved by adding only an ABBE. Also, the demonstration testing was conducted without coding, therefore, coding could also be used to reduce the effects of signal distortions. Also, the computer simulations showed that if a cable equalizer is added to the Ka-Band Ground Terminal, the eye pattern opening will become slightly more open because the signal distortions will be decreased a little.

If better implementation loss performance is required for an operational system, the KaTP project recommends that GSFC install a cable equalizer or an ABBE in the Ka-Band Ground Terminal, use coding, and/or use an improved receiver.

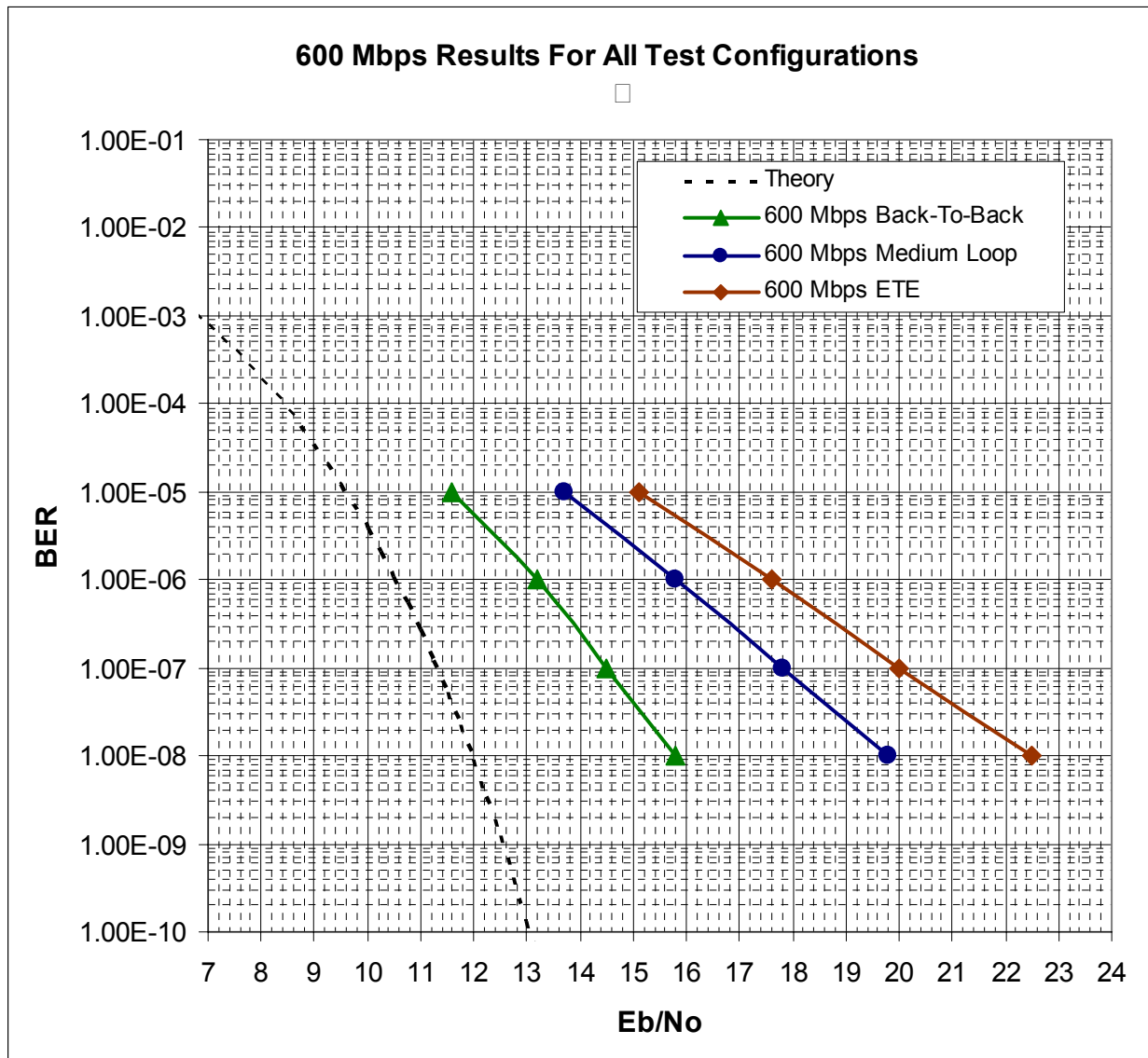


Figure 6-36. 600 Mbps Results For All Test Configurations

Table 6-7. Summary of 600 Mbps Results For All Test Configurations

Test Configuration	BER	50 Mbps Implementation Loss	300 Mbps Implementation Loss	450 Mbps Implementation Loss	600 Mbps Implementation Loss
Back-To-Back Loop Test	10^{-5}	2.7 dB	1.9 dB	1.8 dB	2.0 dB
	10^{-7}	3.1 dB	2.4 dB	2.2 dB	3.2 dB
Medium Loop Test	10^{-5}	3.4 dB	2.9 dB	3.1 dB	4.1 dB
	10^{-7}	4.4 dB	3.5 dB	3.9 dB	6.5 dB
End-To-End Test	10^{-5}	3.7 dB	3.7 dB	4.7 dB	5.5 dB
	10^{-7}	5.1 dB	4.3 dB	5.8 dB	8.7 dB

**Table 6-8. Summary of 600 Mbps Computer Simulation Results
(Includes Worst-Case Customer Constraint Values)**

Receiver Configuration		Equalization Configuration			Total Implementation Loss at 10 ⁻⁵ BER
Back-To-Back Receiver Implementation Loss	Method for Introducing Receiver Back-To-Back Implementation Loss	Cable Equalization		Adaptive Baseband Equalizer	
		Gain Equalizer	Phase Equalizer		
2.0 dB	Cross Talk	No	No	No	4.07 dB
		No	No	Yes	2.79 dB
		Yes ⁽²⁾	Yes ⁽³⁾	No	3.36 dB
		Yes ⁽²⁾	Yes ⁽³⁾	Yes	2.89 dB
	Ripple Gain Flatness and Phase Nonlinearity ⁽¹⁾	No	No	No	5.52 dB
		No	No	Yes	3.59 dB
		Yes ⁽²⁾	No	No	5.22 dB
		Yes ⁽²⁾	No	Yes	3.81 dB
		Yes ⁽²⁾	Yes ⁽³⁾	No	3.96 dB
		Yes ⁽²⁾	Yes ⁽³⁾	Yes	3.20 dB
2.5 dB	Cross Talk	No	No	No	4.80 dB
		No	No	Yes	3.43 dB
		Yes ⁽²⁾	Yes ⁽³⁾	No	4.02 dB
		Yes ⁽²⁾	Yes ⁽³⁾	Yes	3.51 dB
	Ripple Gain Flatness and Phase Nonlinearity ⁽¹⁾	No	No	No	6.85 dB
		No	No	Yes	4.26 dB
		Yes ⁽²⁾	No	No	6.34 dB
		Yes ⁽²⁾	No	Yes	4.57 dB
		Yes ⁽²⁾	Yes ⁽³⁾	No	4.94 dB
		Yes ⁽²⁾	Yes ⁽³⁾	Yes	3.98 dB

Notes:

1. While there are many ways to introduce receiver loss, such as, cross-talk and mis-tuned data detection filters, the ripple gain flatness and phase nonlinearity approach generally give worst-case results.
2. Gain equalizer removes tilt in measurement data. Total gain flatness reduced from 4.1dB p-to-p to 1.1 dB p-to-p (over ± 230 MHz).
3. Phase equalizer removes parabola in measurement data. Total phase nonlinearity reduced from 46.3° p-to-p to 13.82° p-to-p (over ± 230 MHz).

6.5.2 Minimum Prec

This paragraph includes the predicted minimum received power (Prec) that a Ka-Band customer spacecraft would need to provide at the ground terminal antenna when transmitting 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps when using the test receiver. See reference [e], Appendix A for a more detailed discussion on Prec. The minimum Prec calculations in this section assume a 1.0E-05 BER and no link margin. The minimum Prec calculations also assume that the ground terminal G/T is 32.5 dB/K which is the specified value provided by the ground terminal antenna manufacturer. The minimum Prec for a 1.0E-05 BER link is a function of the Eb/No results at a 1.0E-05 BER with the test receiver when using SQPSK modulation. If another receiver is used, the Eb/No results and minimum Prec results will change.

Figure 6-37 depicts the ground terminal link budget for the 600 Mbps minimum Prec calculations. The customer spacecraft EIRP that will be required to produce that Prec at 25.7 GHz will be a function of parameters that include spacecraft altitude, rain attenuation, spacecraft antenna pointing accuracy, and atmospheric loss. The 1.0E-05 BER minimum Precs for 50 Mbps, 300 Mbps, 450 Mbps, and 600 Mbps when using the test receiver are -170.8 dBWi, -163.0 dBWi, -160.3 dBWi, and -158.2 dBWi (line 1 on Figure 6-37), respectively.

#	Parameter	Value	Unit	Notes
1	P _{rec} at ground terminal	-158.2	dBWi	Required signal power at ground terminal antenna to achieve 1.0E-05 BER with 0 dB margin (assuming TSI receiver with good bit synchronization).
2	Ground terminal G/T	32.5	dB/K	32.5 is Vendor specified value
3	Boltzmann's constant	-228.6	dBW/Hz-K	
4	C/N ₀ at ground terminal	102.9	dB-Hz	
5	Data rate	87.8	dB above 1 bps	600 Mbps in dB units
6	Received E _b /N ₀ at ground terminal	15.1	dB	
7	Link Implementation Loss	5.5	dB	GN Demo results, Table 6-7 (600 Mbps, uncoded, and 1.0E-05 BER).
8	Theoretical Eb/No	9.6	dB	QPSK uncoded, 1.0E-05 BER
9	BER margin	0.0	dB	System Margin

Figure 6-37. 600 Mbps Minimum Prec Calculation

6.5.3 Spectrum Analyzer Results

All of the spectrum analyzer plots for all test configurations show typical spectral shapes for each data rate. The spectrum analyzer results were as expected.

6.5.4 Eye Pattern Results

As expected, the Back-to-Back, Medium Loop, and End-To End eye patterns for 600 Mbps show that as the signal distortions increase, the eye opening becomes slightly less open. As expected, the computer simulations discussed above in paragraph 6.5.1 showed that if a cable equalizer is added to the Ka-Band Ground Terminal, the eye opening would become slightly more open because the signal distortions would be decreased a little.

6.6 Test Receiver Performance During BER Demonstration

The Ka-Band Ground Terminal performance varied as a function of data rate. This variation in performance can be partly attributed to the test receiver performance:

- a. The test receiver performed well at 300 Mbps and 450 Mbps. The receiver can be used operationally at 300 Mbps and 450 Mbps.
- b. The test receiver performance at 50 Mbps is acceptable for operations, but the receiver does have slightly non-optimal performance at 50 Mbps. The 50 Mbps eye patterns for the Back-To-Back, Medium Loop, and End-To-End tests show signals with the same slightly excessive distortion characteristic at the output of the receiver matched filter. Because the same 50 Mbps distortion characteristic existed during all tests, it appears that the distortions were produced in the receiver, not in the ground terminal equipment chain.
- c. The test receiver performance at 600 Mbps should be improved before the receiver is used operationally at 600 Mbps. The 600 Mbps performance during the demonstration was achieved only by bypassing the receiver bit synchronizer and using the Agilent 86130A BERTS as the bit synchronizer. Using the BERTS as a bit synchronizer is not possible in an operational environment because the data is not accessible after the BERTS. The BERTS only calculates the BER rate based on the chosen PRBS. Also, the receiver Back-To-Back implementation loss was only 2.0 dB even while using the Agilent 86130A as the bit synchronizer.

Section 7. Results Of Antenna Autotracking Test

This section presents the detailed demonstration results for the Antenna Autotrack portion of the demonstrations.

Before conducting the antenna autotrack demonstration, WFF personnel verified that the new Ka-band ground terminal was operating properly and within the specifications defined in the KaTP Systems Requirements Document (SRD). Therefore, the demonstration started after the relevant system acceptance tests were completed.

7.1 Ground Terminal and Helicopter Test Configuration

During the antenna acquisition demonstrations, the KaTP test team characterized the performance of the Ka-Band Ground Terminal antenna autotrack system at Ka-band and S-band while tracking a Langley Research Center (LRC) UH-1 helicopter that transmitted Ka-band and S-band signals. A helicopter was used during the demonstrations because no Ka-band orbiting spacecraft were available for testing. Figure 7-1 depicts the ground terminal and helicopter test configuration. Figures 7-2 through 7-5 contain photos of the test equipment that was placed inside and on the helicopter. The radio frequency (RF) test equipment was mounted in a 19" rack inside the helicopter.

The test equipment on board the helicopter included CW generators at Ka-band and S-band. The S-band generator output was connected directly to the S-band linear polarized blade antenna. For different test events, the KaTP test team switched the Ka-band circular polarized antenna between a Ka-band RF generator and the GSFC in-house Ka-band 150 Mbps QPSK modulator. The GSFC Microwave & Communications Systems Branch provided the GSFC in-house Ka-band modulator. The modulator output frequency was 26.5 GHz and an Agilent PN generator was used as the data source.

7.2 Test Methods

The helicopter flew in a four mile radius circular pattern around the Ka-band ground terminal in order to simulate a customer spacecraft with Low Earth Orbit (LEO) range dynamics as best as possible. The helicopter flight plan contained way points that were distributed around the circular pattern in 10 degrees increments.

The tests were conducted with signals transmitted with different modulations, polarizations, frequencies, and antenna angular velocities. The SNRs were recorded at the ground terminals.

The test team used the manual handwheels of the 3862 antenna control unit (ACU) in the Ka-band ground terminal to initially acquire the S-band signal of the helicopter. Locating the helicopter was aided by the flight crew who relayed the upcoming way point on the circle to the ground terminal test team. Then, after receiving the way point information from the flight crew, the test team used the manual handwheels to point the ground terminal antenna at that upcoming waypoint. After S-band signal acquisition, the S-band autotrack was selected manually. Then, after several seconds of S-band autotracking, the test team manually selected the Ka-band autotrack.

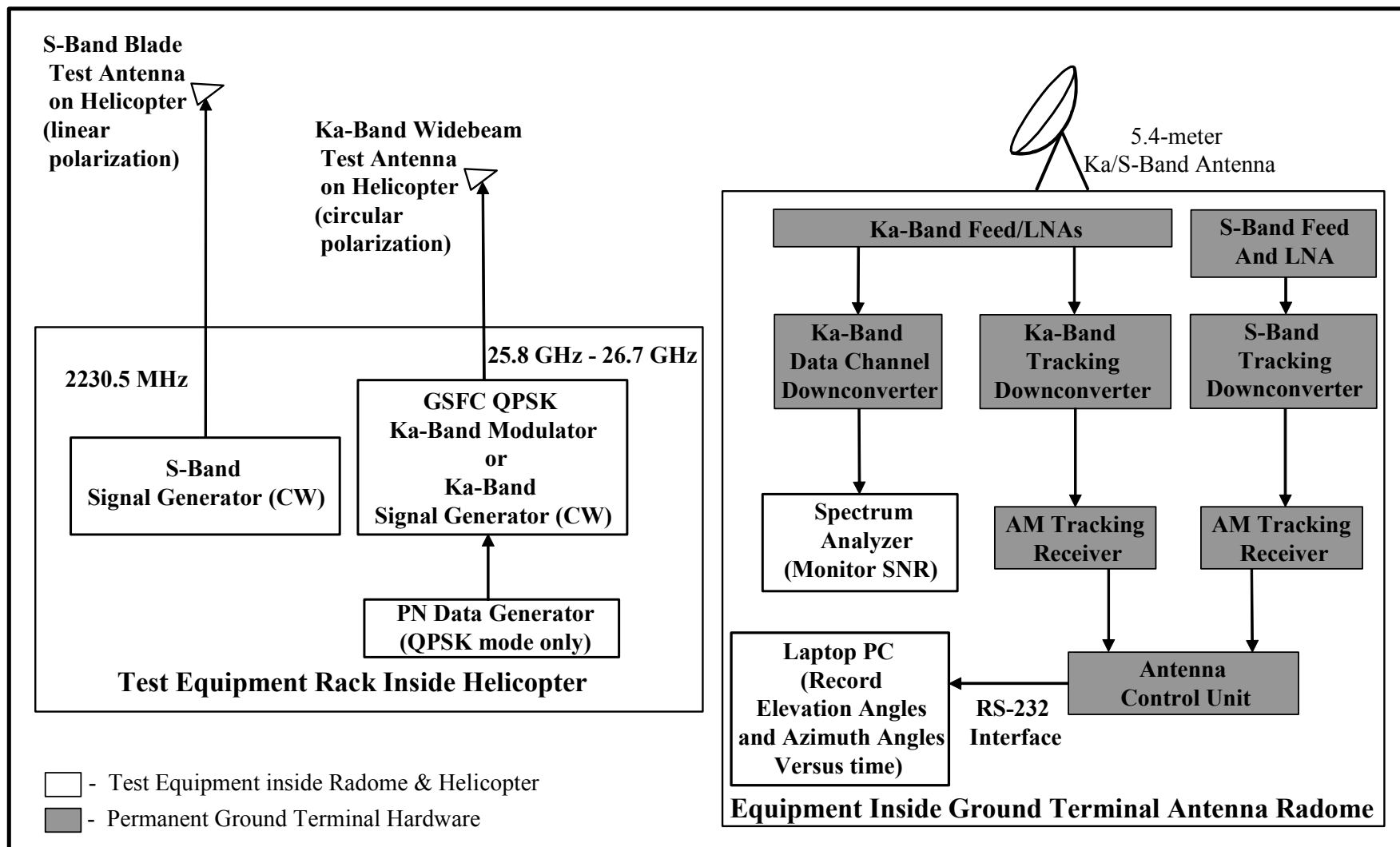


Figure 7-1. Ground Terminal and Helicopter Test Configuration



Figure 7-2. Helicopter Test Equipment



Figure 7-3. Ka-band Circular polarized (RHCP & LHCP) broadbeam antenna (Close-up)



Figure 7-4. Ka-band Circular polarized (RHCP and LHCP) broadbeam antenna

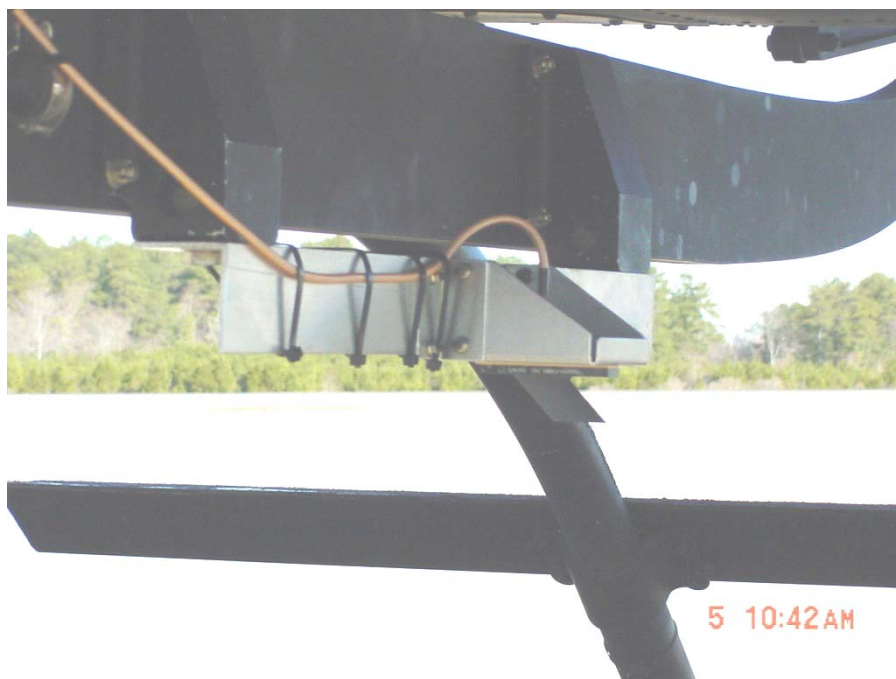


Figure 7-5. S-band Blade Antenna Mounted On Bottom Of Helicopter

7.3 Test Results

Once a successful Ka-band lock occurred, the ground terminal did not drop the Ka-band autotrack until the test team manually de-selected it.

The helicopter alternately transmitted QPSK signals and CW signals. The KaTP test team recorded all of the autotrack acquisition times and other performance characteristics. The test team also recorded the antenna pointing information on a laptop personal computer (PC). The angle information was obtained from the 3862 ACU RS232 time stamped angle output. Table 7-1 summarizes the antenna autotrack test events and results for the flight test.

The antenna angle data and antenna angle rate data for the four test events listed in Table 7-1 are plotted in Figures 7-6 to 7-25. The figures show the antenna elevation angle data, antenna X-axis and Y-axis angle data, and antenna X-axis and Y-axis angle rate data. Based on a typical Terra spacecraft pass over WFF, a spacecraft pass requires that the ground terminal maintain autotrack at angle rates up to 2.0 degrees per second. Although most of the tracking during the helicopter demonstration was for angle rates below 2 degrees/second, Figure 7-13 shows that the ground terminal successfully autotrack the helicopter at a 2.2 degrees per second rate when the helicopter made rapid maneuvers while it returned to WFF for a flight test break.

The KaTP test team demonstrated that the Ka-Band Ground Terminal can manually acquire and autotrack a moving Ka-Band signal source. However, when a Ka-band orbiting spacecraft becomes available for testing, the test team recommends that NASA conduct an antenna autotracking demonstration with the spacecraft. The spacecraft demonstration should include an automatic Ka-band acquisition while using the program track mode for initial acquisition.

Table 7-1. Antenna Autotrack Test Events and Results

Test Event	Frequency	Modulation	Polarization	Signal-To-Noise Ratio	Ground Terminal Antenna Elevation Angle
1	25.8 GHz	CW	RHCP	15 dB	13 degrees average
2	26.5 GHz	QPSK at 150 Mbps	RHCP	10 dB	13 degrees average
3	26.7 GHz	CW	RHCP	16 dB	5.5 degrees average
4	26.7 GHz	CW	LHCP	20 dB	5.5 degrees average

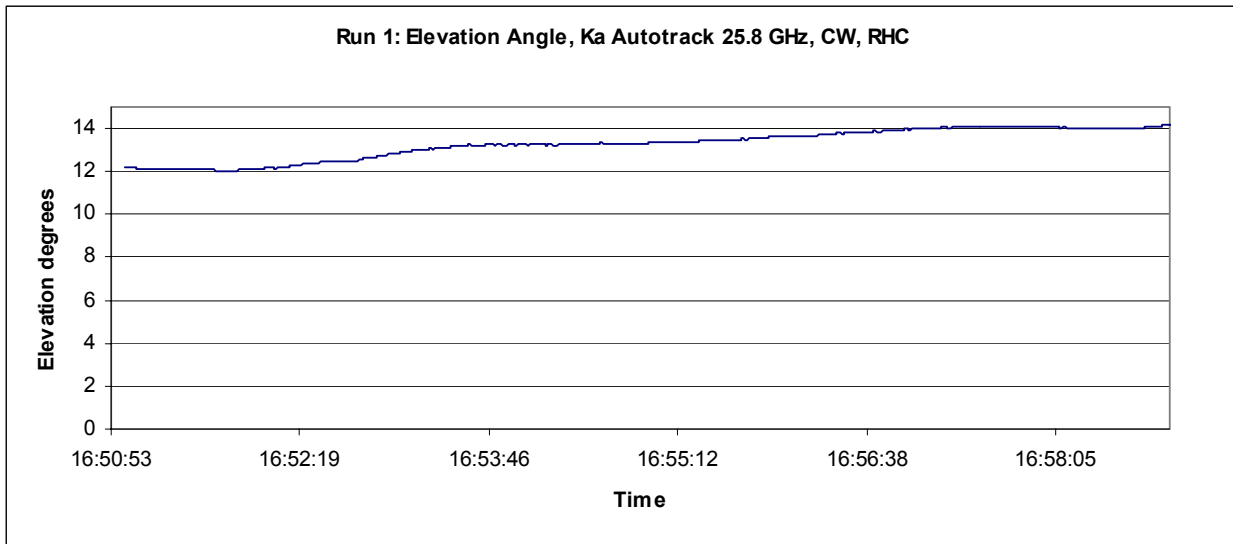


Figure 7-6. Test Event 1, Elevation Angle, 25.8 GHz RHCP CW

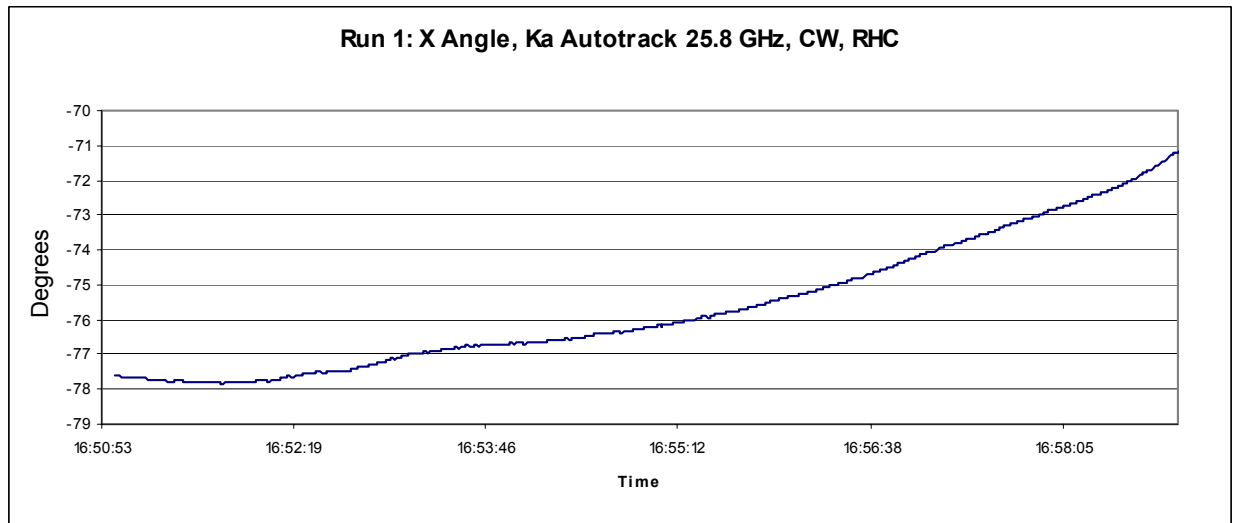


Figure 7-7. Test Event 1, X Angle, 25.8 GHz RHCP CW

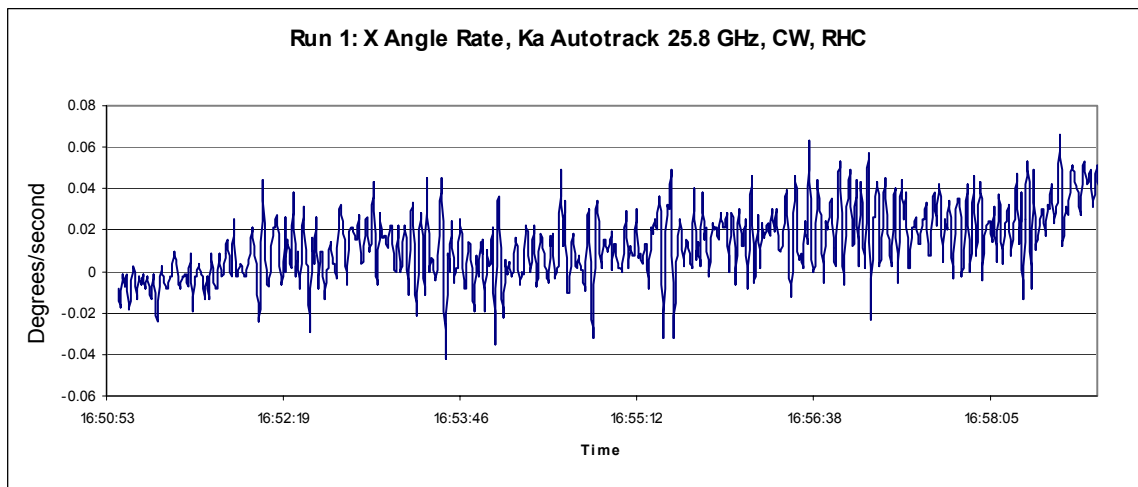


Figure 7-8. Test Event 1, X Angular Rate, 25.8 GHz RHCP CW

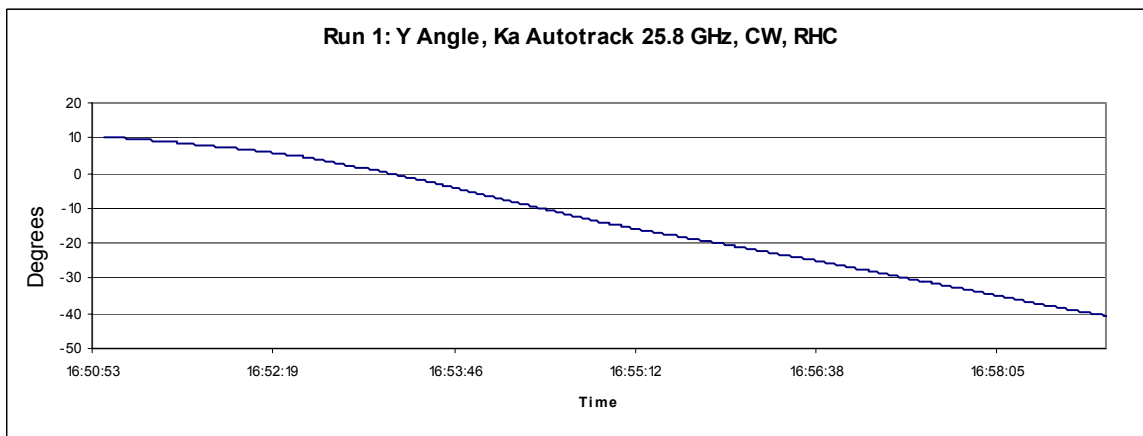


Figure 7-9. Test Event 1, Y Angle, 25.8 GHz RHCP CW

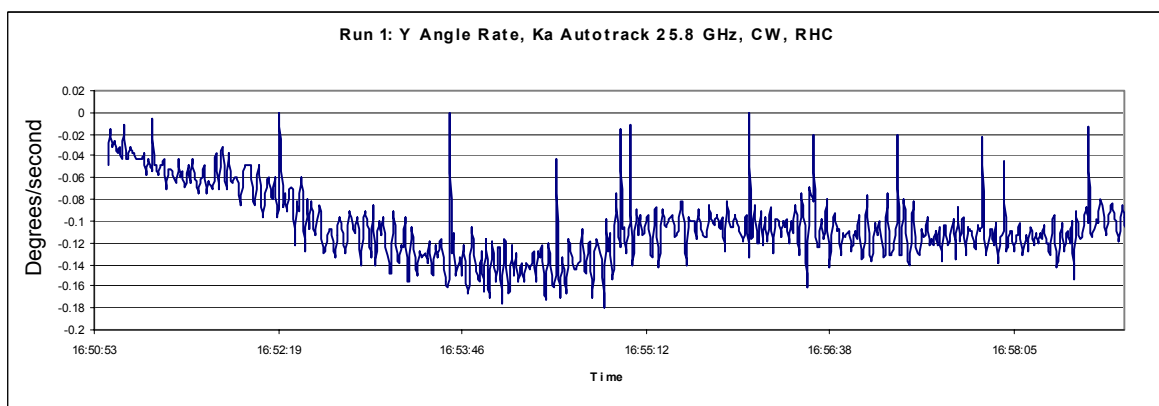


Figure 7-10. Test Event 1, Y Angular Rate, 25.8 GHz RHCP CW

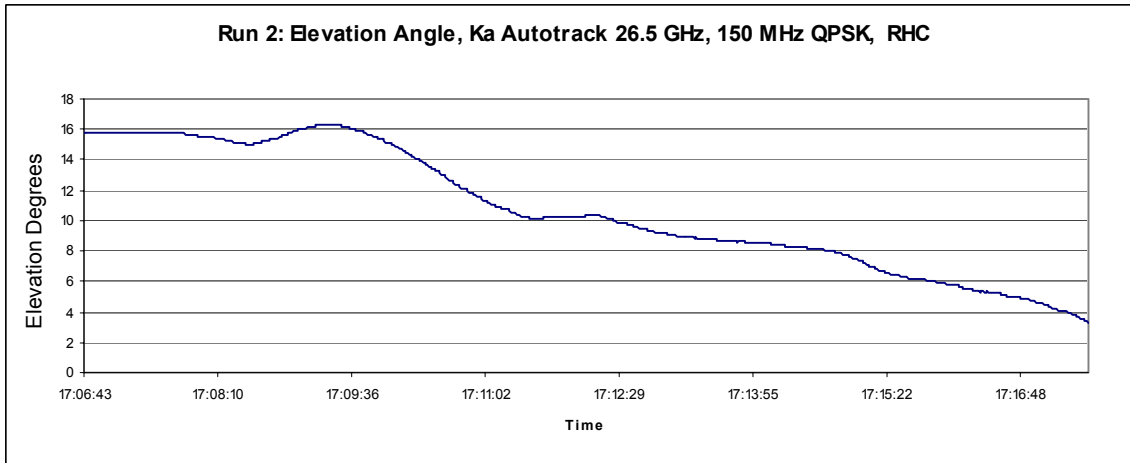


Figure 7-11. Test Event 2, Elevation Angle, 26.5 GHz RHCP, 150 Mbps QPSK

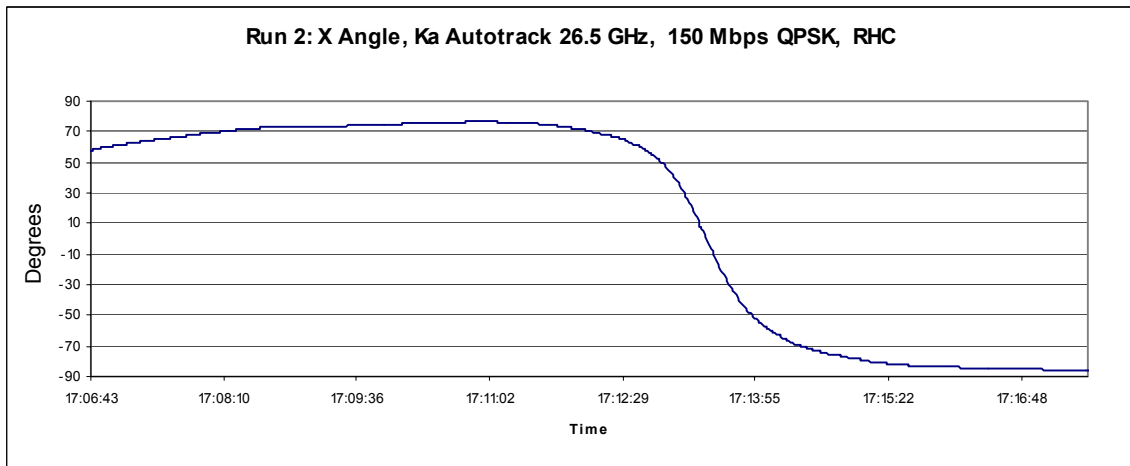


Figure 7-12. Test Event 2, X Angle, 26.5 GHz RHCP, 150 Mbps QPSK

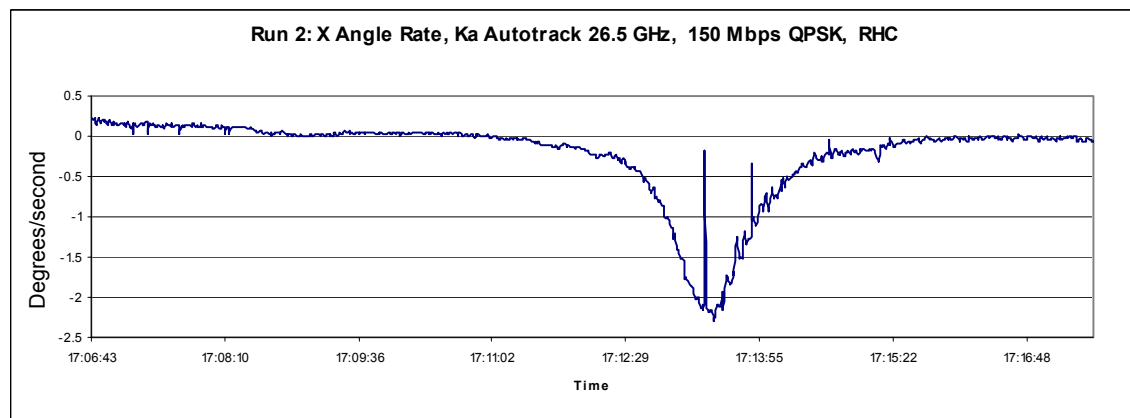


Figure 7-13. Test event 2, X Angular Rate, 26.5 GHz RHCP, 150 Mbps QPSK

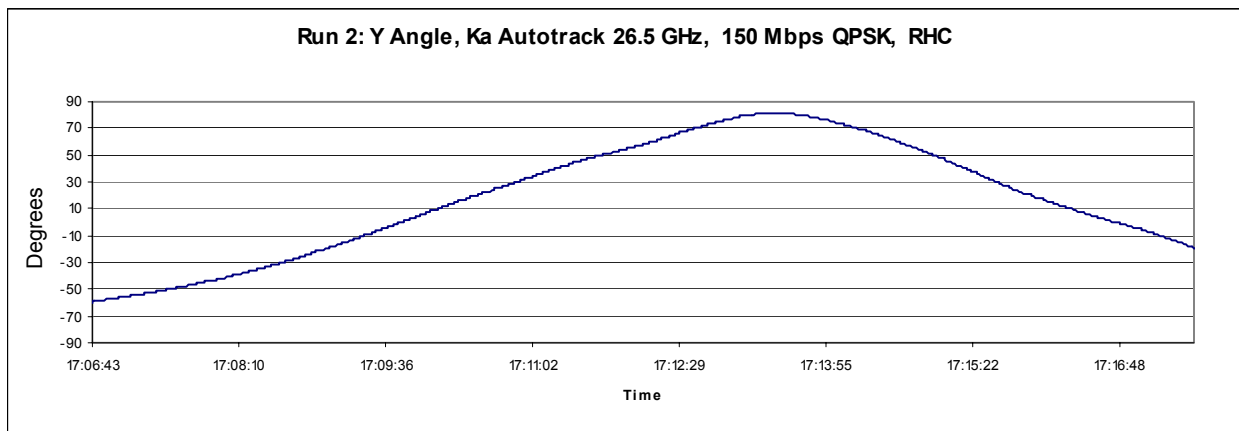


Figure 7-14. Test Event 2, Y Angle, 26.5 GHz RHCP, 150 Mbps QPSK

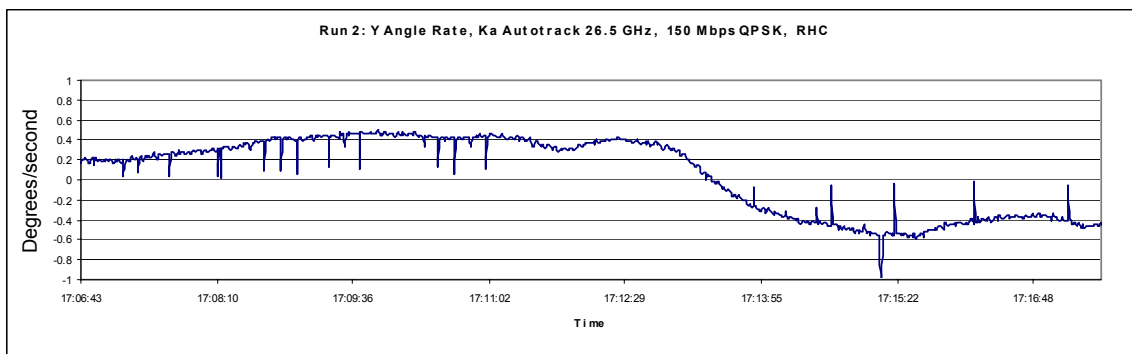


Figure 7-15. Test Event 2, Y Angular Rate, 26.5 GHz RHCP, 150 Mbps QPSK

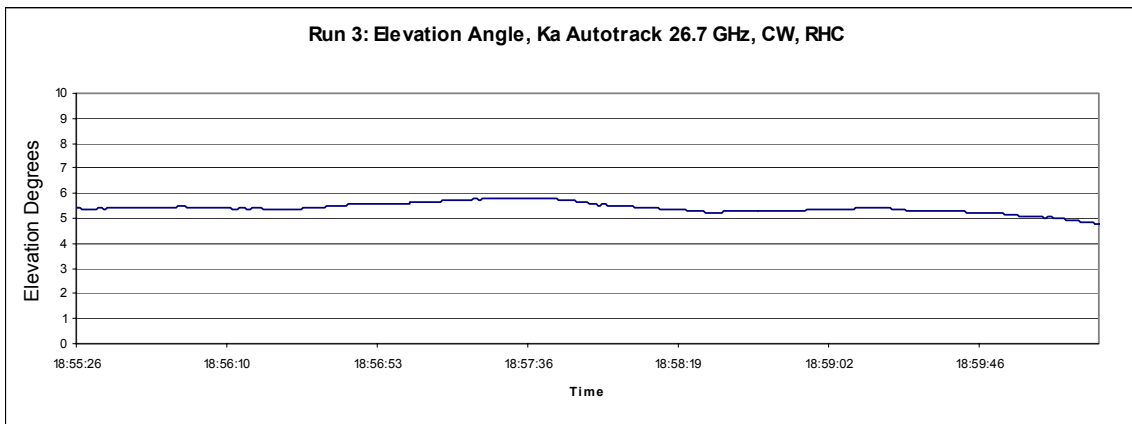


Figure 7-16. Test Event 3, Elevation Angle, 26.7 GHz RHCP CW

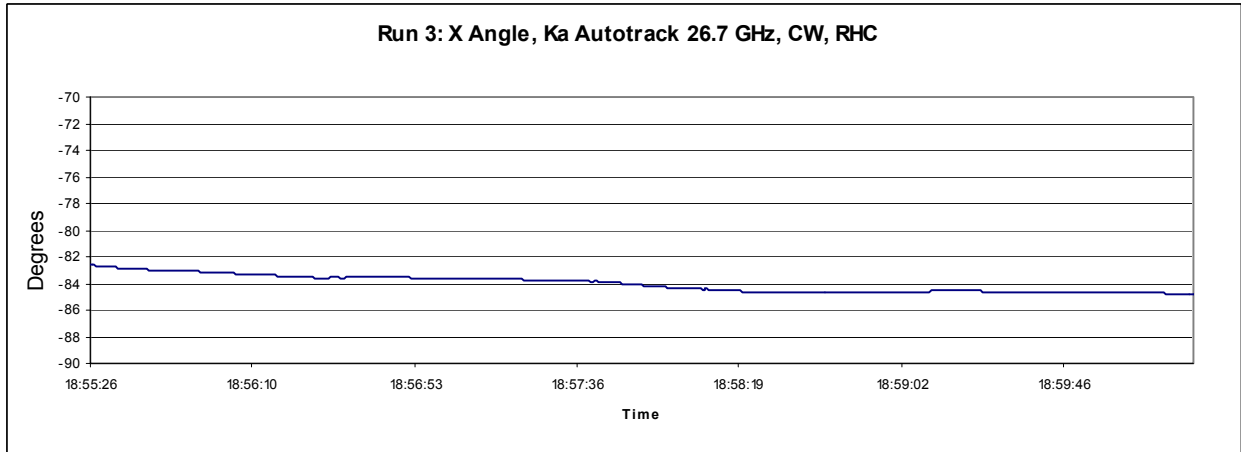


Figure 7-17. Test Event 3, X Angle, 26.7 GHz RHCP CW

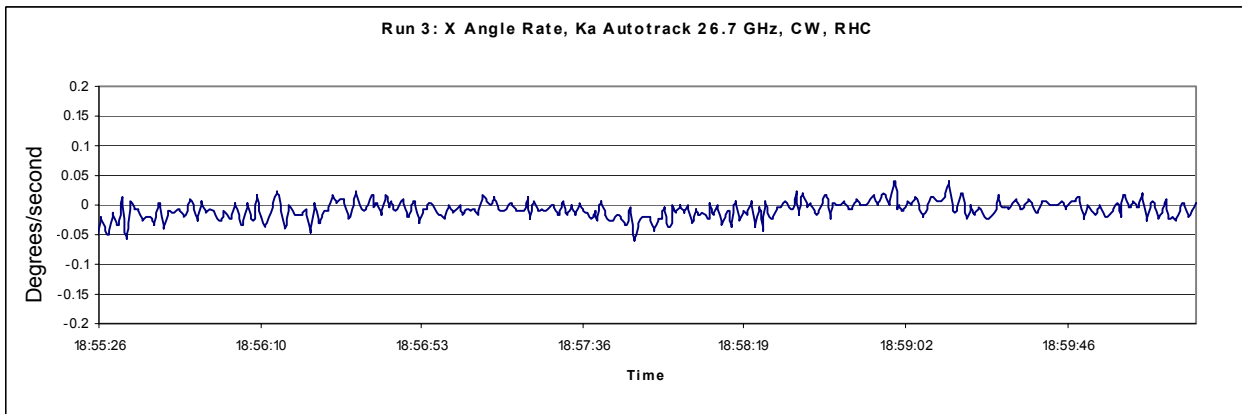


Figure 7-18. Test Event 3, X Angular Rate, 26.7 GHz RHCP CW

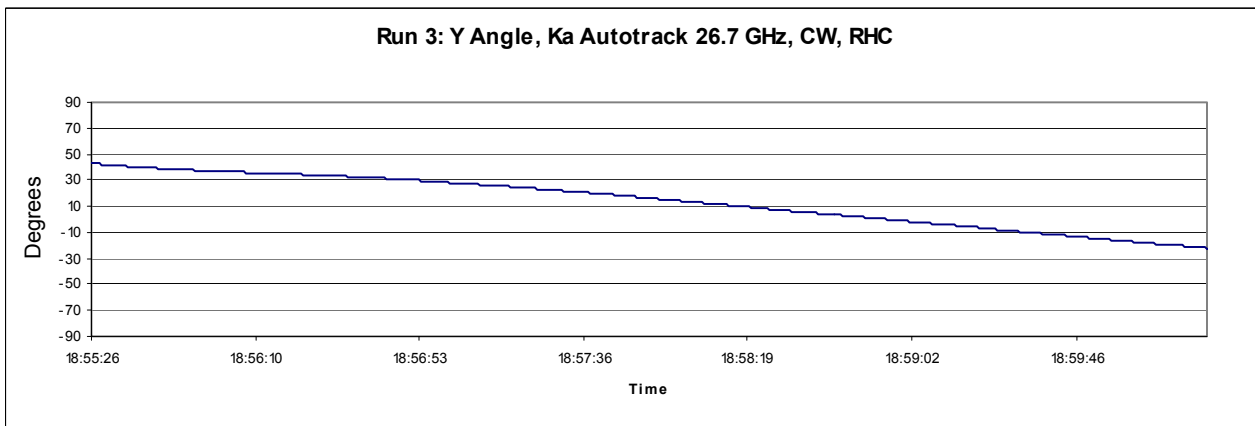


Figure 7-19. Test Event 3, Y Angle, 26.7 GHz RHCP CW

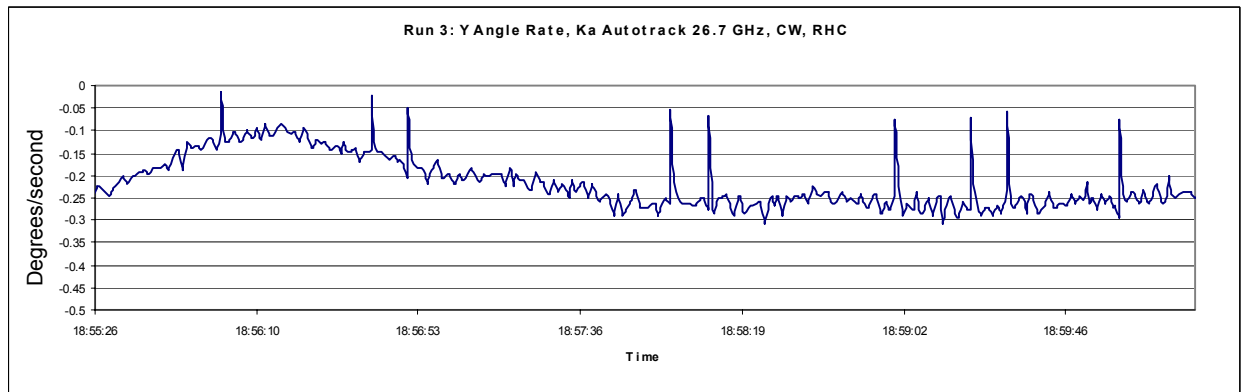


Figure 7-20. Test Event 3, Y Angular Rate, 26.7 GHz RHCP CW

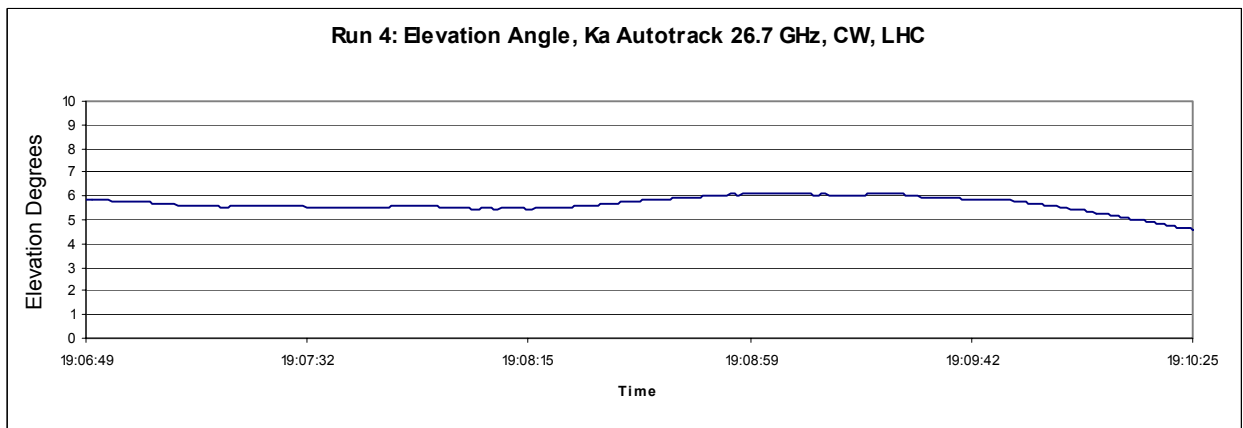


Figure 7-21. Test Event 4, Elevation Angle, 26.7 GHz LHCP CW

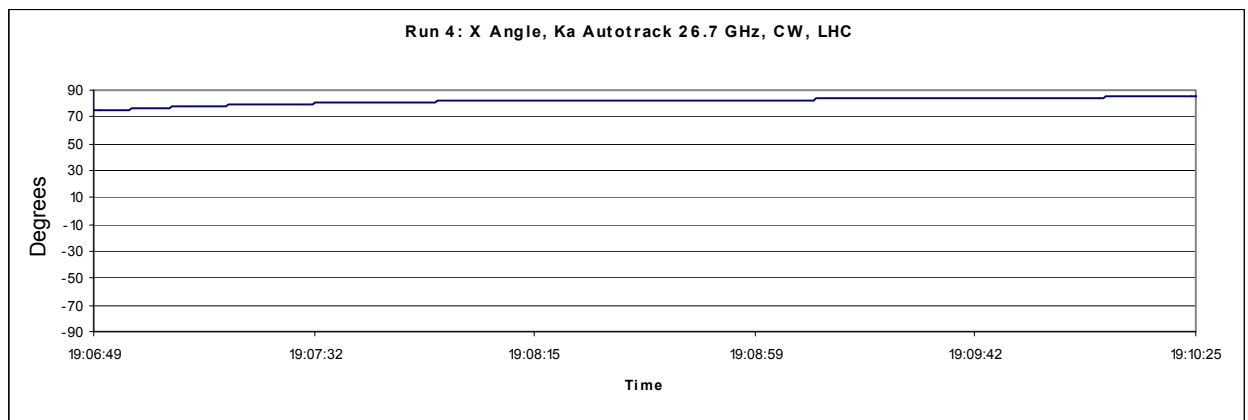


Figure 7-22. Test Event 4, X Angle, 26.7 GHz LHCP CW

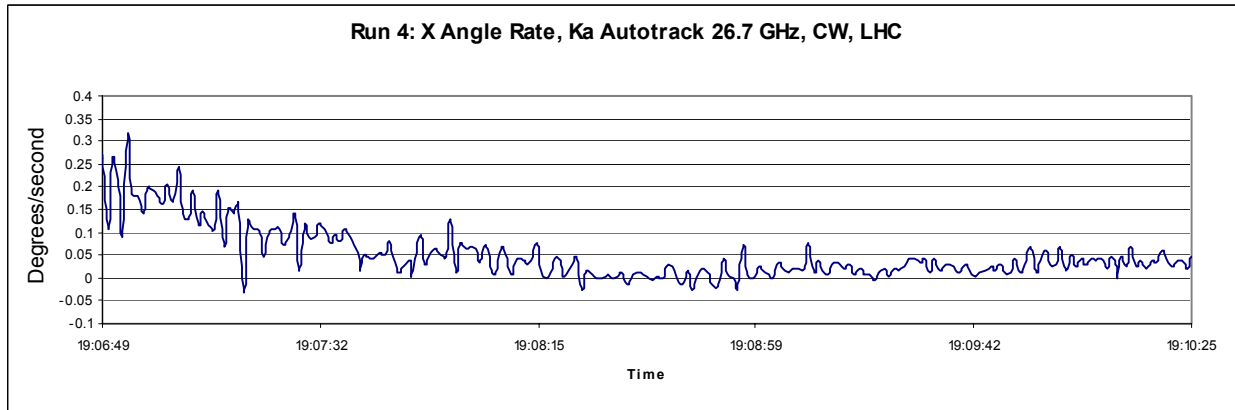


Figure 7-23. Test Event 4, X Angular Rate, 26.7 GHz LHCP CW

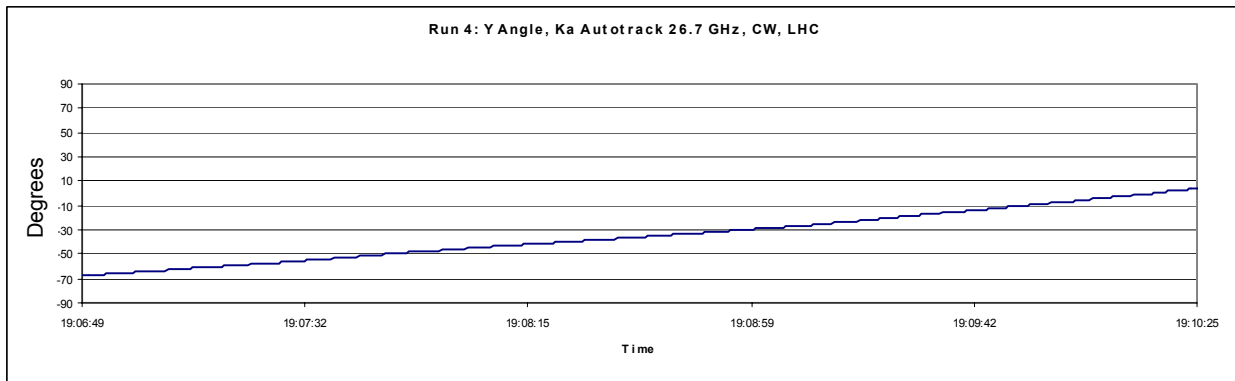


Figure 7-24. Test Event 4, Y Angle, 26.7 GHz LHCP CW

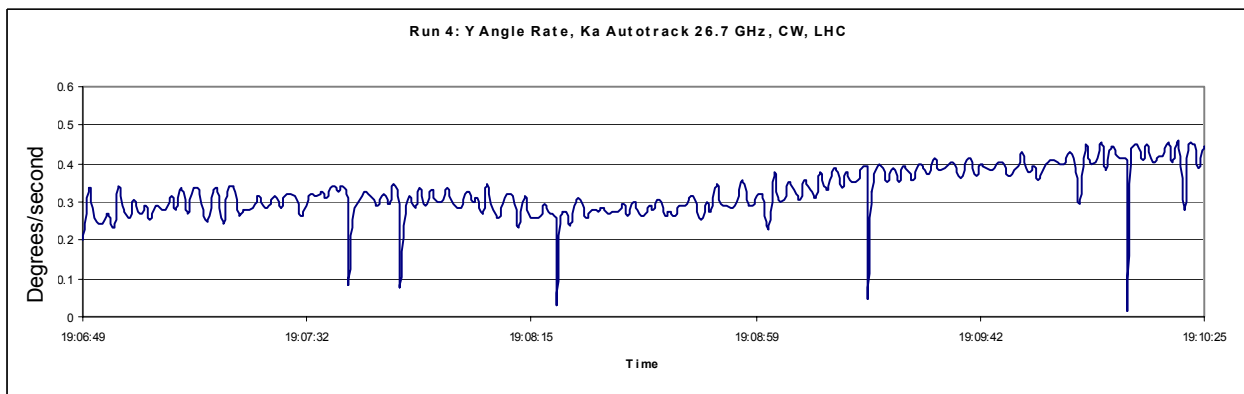


Figure 7-25. Test Event 4, Y Angular Rate, 26.7 GHz LHCP CW

Section 8. Conclusions

1. The KaTP project successfully demonstrated that the Ka-Band Ground Terminal can support uncoded data rates up to 600 Mbps and that the Goddard Space Flight Center (GSFC) can consider using the Ka-Band Ground Terminal as a test-bed to support Ka-Band technology developments like the GSFC High Rate User Ka-Band Phased Array Antenna.
2. Based on the E_b/N_o results in section 6.5 that were produced during the various characterization tests (Back-To-Back, Medium Loop, and End-To-End), the test team successfully characterized the subsystem contributions to the implementation losses.
3. The Ka-Band Ground Terminal implementation loss performance is not good enough for an operational GN link (For example, a 5.5 dB implementation loss at $1.0E-05$ BER at 600 Mbps), however, 1.4 dB of the implementation loss at 600 Mbps was caused by the available test transmitter system at the bore-site tower. Also, computer simulations indicated that a 3.36 dB implementation loss at 600 Mbps and a $1.0E-05$ BER can be achieved by adding a cable equalizer that removes the gain versus frequency tilt characteristic and parabolic phase characteristic that exist in the Ka-band Ground Terminal. The computer simulations indicated that a 2.79 dB implementation loss improvement can be achieved by adding only an ABBE. Also, the demonstration testing was conducted without coding, therefore, coding could also be used to reduce the effects of signal distortions. Also, the receiver Back-To-Back implementation loss was only 2.0 dB even while using the Agilent 86130A as the bit synchronizer. If better implementation loss performance is required for an operational system, the KaTP project recommends that GSFC install a cable equalizer or an ABBE in the Ka-Band Ground Terminal, use coding, and/or use an improved receiver.
4. During the End-To-End BER portion of the demonstration, the test team used a boresite tower as the transmit source because an orbiting spacecraft was not available for testing. Therefore, when a Ka-band orbiting spacecraft becomes available for BER testing at any data rate, the test team recommends that GSFC conduct BER tests with that spacecraft at Ka-band.
5. The KaTP test team successfully demonstrated that the Ka-band Ground Terminal can manually acquire and autotrack a moving Ka-Band signal source. However, when a Ka-band orbiting spacecraft becomes available for testing, the test team recommends that GSFC conduct an antenna autotracking demonstration with the spacecraft. The spacecraft demonstration should include an automatic Ka-band acquisition while using the program track mode for initial acquisition.
6. The test receiver can be used operationally at 50 Mbps, 300 Mbps, and 450 Mbps, but the test receiver performance at 600 Mbps should be improved before the receiver is used operationally at 600 Mbps. (The 600 Mbps performance during the demonstration was achieved only by bypassing the test receiver bit synchronizer.)

Section 9. Acronyms

ACU	Antenna Control Unit
AGC	Automatic Gain Control
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BERTS	Bit Error Rate Test System
CW	Continuous Wave
EIRP	Effective Isotropic Radiated Power
FOTS	Fiber Optic Transmission System
GN	Ground Network
GSFC	Goddard Space Flight Center
HDR	High Data Rate
HDRR	High Data Rate Receiver
HPA	High Power Amplifier
IF	Intermediate Frequency
KaTP	Ka-Band Transition Product
LEO	Low Earth Orbit
LHCP	Left-Hand Circular Polarized
LNA	Low Noise Amplifier
LRC	Langley Research Center
NASA	National Aeronautics and Space Administration
PC	Personal Computer
PMP	Product Management Plan
PN	Pseudo-noise
POC	Point Of Contact
PRBS	Psuedo Random Bit Stream
Prec	Received Power
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RHCP	Right-Hand Circular Polarized

SNR	Signal-to-Noise Ratio
SQPSK	Staggered Quadrature Phase Shift Keying
SRD	System Requirements Document
WFF	Wallops Flight Facility